BUFFALO GRAIN ELEVATORS
Buffalo
Erie County
New York

HAER No. NY-239

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HISTORIC AMERICAN ENGINEERING RECORD

BUFFALO GRAIN ELEVATORS
HAER No. NY-239

Location: Buffalo, Erie County, New York

Date: 1897-1954

Designer: Multiple; see individual elevator reports listed on p.2

Builder: Multiple; see individual elevator reports listed on p.2

Status: Variable; see individual elevator reports listed on p.2

Significance: The grain elevators of Buffalo comprise the most outstanding collection of extant grain elevators in the United States, and collectively represent the variety of construction materials, building forms, and technological innovations that revolutionized the handling of grain in this country.

Project Information: The documentation of Buffalo's grain elevators was prepared by the Historic American Engineering Record (HAER), National Park Service, in 1990 and 1991. The project was co-sponsored by the Industrial Heritage Committee, Inc., of Buffalo, Lorraine Pierro, President, with the cooperation of The Pillsbury Company, Mark Norton, Plant Manager, Walter Dutka, Senior Mechanical Engineer, and with the valuable assistance of Henry Baxter, Henry Wollenberg, and Jerry Malloy. The HAER documentation was prepared under the supervision of Robert Kapsch, Chief, HABS/HAER, and Eric DeLony, Chief and Principal Architect, HAER. The project was managed by Robbyn Jackson, Architect, HAER, and the team consisted of: Craig Strong, Supervising Architect; Todd Croteau, Christopher Payne, Patricia Reese, architects; Thomas Leary, Supervising Historian; John Healey, and Elizabeth Sholes, historians. Large-format photography was done by Jet Lowe, HAER photographer.

Historians: Thomas E. Leary, John R. Healey, and Elizabeth C. Sholes, 1990-1991 (The overview history in HAER No. NY-239 was written by John R. Healey.)

This is one in a series of HAER reports for the Buffalo Grain Elevator Project. HAER No. NY-239, "Buffalo Grain Elevators," contains an overview history of the elevators. The following elevators have separate reports:

NY-240 Great Northern Elevator
NY-241 Standard Elevator
NY-242 Wollenberg Grain & Seed Elevator
NY-243 Concrete-Central Elevator
NY-244 Washburn Crosby Elevator
NY-245 Connecting Terminal Elevator
NY-246 Spencer Kellogg Elevator
NY-247 Cooperative Grange League Federation
NY-248 Electric Elevator
NY-249 American Elevator
NY-250 Perot Elevator
NY-251 Lake & Rail Elevator
NY-252 Marine "A" Elevator
NY-253 Superior Elevator
NY-254 Saskatchewan Cooperative Elevator
NY-256 Urban Elevator
NY-257 H-O Oats Elevator
NY-258 Kreiner Malting Elevator
NY-259 Meyer Malting Elevator
NY-260 Eastern States Elevator

In addition, the Appendix of HAER No. NY-239 contains brief notations on the following elevators:

Buffalo Cereal Elevator
Cloverleaf Milling Co. Elevator
Dakota Elevator
Dellwood Elevator
Great Eastern Elevator
Iron Elevator
John Kam Malting Elevator
Monarch Elevator
Pratt Foods Elevator
Ralston Purina Elevator
Riverside Malting Elevator

BUFFALO GRAIN ELEVATORS
OVERVIEW REPORT

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INTRODUCTION

The development of the Great Lakes grain trade created unrivalled concentrations of grain elevators in the ports of Duluth and Buffalo in the U.S. and in the Thunder Bay region of Canada.[1] Of these elevator groupings, those in Buffalo became particularly famed sources of inspiration for European proponents of the International Style of architecture. Le Corbusier viewed the American grain elevators and factories as "the magnificent first fruits of the new age," in which "the American Engineers overwhelm with their calculations our expiring architecture."[2]

The aesthetic treatment given to these structures by the architects of the "modern movement" loosely related the forms of the buildings to their functions, but failed to look at the design and construction of these buildings. Subsequent commentators have followed this approach at the expense of a deeper understanding of the evolutionary trends occurring in Buffalo elevator construction and in elevator design throughout America.

Of the three major elevator groupings, that in Buffalo provides the most comprehensive inventory of structures, spanning an era of elevator construction of about 110 years. The city was once well-endowed with representatives of earlier structural forms, particularly those of wood and iron, but only one example of each remains extant. During the twentieth century, about forty individual concrete elevators were built in Buffalo. Although the grain trade suffered a dramatic decline from the late 1950s, Buffalo's legacy of concrete grain elevators remains remarkably intact; the Dellwood and Ralston Purina elevators are the only substantial complexes that have been demolished.

The physical evidence provided by the structures is supplemented by an equally remarkable survival of primary documentary sources. The Buffalo City Hall vaults house a collection of original drawings, contracts, engineering calculations, construction dates and estimated costs. HAER reports of individual elevators have been compiled by collation of city hall documents supplemented by information from contemporary trade journals, fire insurance maps, company records and publications, oral interviews, secondary sources, and a variety of other sources.

Contemporary evaluations of elevator building design and practice are few. The construction of concrete elevators was concentrated in the hands of a small group of specialist companies. The lack of coverage by the engineering and construction press may have been due to a proprietorial attitude on behalf of elevator construction companies anxious to protect their position. Despite the absence of contemporary descriptions of evolutionary developments in elevator design, primary sources available in Buffalo provide a uniquely large and detailed sample of concrete elevator construction methods. The following overview history attempts to identify changes and trends in elevator building practice, and to explain these observations both by reference to contemporary construction and engineering practice, and by analysis of particular requirements of individual promoters.

THE WOODEN ELEVATOR

Situated at a natural point of transshipment on the route eastward to the eastern seaboard of the United States and to Europe, Buffalo's grain trade benefitted from the development of agriculture on the western prairies during the last quarter of the nineteenth century. By 1894, thirty-six grain elevators with an aggregate capacity of 15,430,000 bushels were equipped to receive, store, condition and ship grain from the Buffalo waterfront. In both function and form, their lineage descended from the principles and practices established by Joseph Dart in the first elevator built on the Buffalo waterfront in 1842. Dart's building was comprised of a series of grain bins above which was a "cupola" containing weighing and spouting equipment. Incoming grain was elevated to the top of the cupola and spouted by gravity via weighing hoppers to storage. Outgoing grain was drawn off from the bottom of the storage bins to be raised once more to the top of the cupola, where it was weighed out and spouted to barge, train or wagon.

The elevator's marine leg was crucial to these functions. Dart's pioneering application of this technology permitted grain to be raised with ease by means of a series of scoop-like buckets attached to a continuous belt. Dart deployed the elevator leg in two distinctly different forms; the "stiff leg" elevated grain in the elevator house, within which it was fixed, and the "loose leg" elevated grain from ships into the elevator house. When not in use, the loose leg was stored in a raised position within the elevator house, requiring a distinctive tower above the cupola roof. If a ship's cargo was to be discharged, the loose leg could be lowered directly into the hold.

Dart's elevator established enduring principles of grain handling and storage. By 1894 developments in the speed and diversity of grain transfer systems had promoted a corresponding evolution in building form. The application of horizontal transfer systems dramatically affected the overall capacity of the storage house. In the absence of horizontal transfer systems, all bins had to be in sufficiently close proximity to the elevator leg to receive grain by direct gravity spouting. Horizontal conveyors permitted the transfer of grain to bins at a distance from the fixed elevator leg. The most economical application of horizontal transfer systems determined that bins should be arranged in elongated rows so that the maximum number of bins might be served by the minimum number of conveyors.

The disposition of conveying equipment had a dramatic effect on the form of the elevator. Where conveyors were only installed above the storage bins, the classic high cupola house became typical. The high cupola extending the length of the building accommodated the heads of a row of elevating legs, together with their associated scale and garner hoppers. Although incoming grain could be distributed to any bin by transfer along bin floor conveyors, the absence of basement conveyors required that outgoing grain, drawn from the bottom of any bin, had to be within direct spouting distance of an elevating leg, so that it might be raised for weighing before shipping out. The Coatsworth and Eastern elevators of the early 1890s typify this form.[3]

The addition of conveying equipment to the basement floor produced a building of radically different appearance. The installation of basement horizontal transfer systems eliminated the need for elevating legs along the length of the structure. Outgoing grain could be spouted onto the basement conveying system and taken to some convenient point in the house where elevator legs were located. Fewer legs were required per unit of storage as outgoing grain from any bin could be directed to a single elevator leg.

The reduction in the number of elevating legs and amount of associated weighing equipment permitted the legs to be grouped at the end of the bins in workhouses occupying a limited area above the bins. The grouping of elevator legs in the workhouse/headhouse style of elevator dispensed with the need for a high cupola above the entire bin floor, requiring only a low cupola or gallery to house the bin floor conveying system. The Lake Shore Elevator of 1886 epitomized this particular style.[4] By this date the loose leg had become housed within an almost self-contained tower, and in 1894 four self-contained movable marine towers housing loose legs were present on the Buffalo waterfront.

The progenitors of the classic concrete elevator featuring elongated bin arrangement, workhouse/headhouse form, and movable marine tower were to be seen in Buffalo by the early 1890s. Although the form of the buildings had evolved to reflect the changes in internal mechanical arrangements, the buildings remained structurally conservative.

With the exception of the Plympton Elevator, all Buffalo elevators were of timber construction. By this time the foundations were likely to consist of a series of concrete piers supported on piles. Timber columns were erected on the piers to the height of the basement. The bin system was supported on a system of longitudinal and transverse beams spanning the columns. The bins were of laminated construction. Continuous lines of 2" planks were laid across the building in both directions, with successive layers spiked one to another to form an interleaving network of rectangular cribbed bins. The width of the timbers varied with height, being typically 10" at the base and 4" at the top. The cupola framework was usually built directly on top of the bins, but could also be supported independently of the bins by foundation columns. Typically, the entire structure was clad in corrugated iron sheathing.[5]

As long as timber remained inexpensive and alternative materials few and costly, the wooden elevator remained preeminent. Yet the wooden elevator was inherently defective as a means of grain storage. The structure was extremely flexible and loaded bins tended to settle, only to recover their dimension upon unloading. The conditions within proved to be an ideal breeding ground for vermin and grain rot. However, the flammable nature of the material was the most serious objection to the wooden elevator, and potential sources of fire were numerous. The grain in storage was liable to overheat, and grain dust explosions were a hazard during transfer operations. Grain dust explosions could easily spread throughout the house, when dust that had accumulated in the many irregularities of the structure was driven into suspension and ignited. Steam-powered elevating and conditioning machinery provided further sources of combustion, as did the smokestacks of ships and locomotives serving the elevator.

Considerable effort was made to minimize fire dangers. Water sprinkler systems were common by 1890, boiler houses were separated from elevators, and railroad car pullers were introduced so that locomotives could be kept at some distance from the elevators. The problem of bin subsidence causing cupola line shafting to overheat was addressed by using telescopic jacks in the basement columns, or eliminating cupola line shafts by the introduction of rope drives from line shafts repositioned in the basement.[6] Composite structural features were also introduced, including concrete floors and steel-framed cupolas.[7]

By the 1890s there is evidence that workhouses, where dust explosions were most likely to occur, were separated from storage houses. The Export Elevator of 1897 was apparently the first wooden Buffalo elevator to feature this form, which was later widely adopted elsewhere in steel and early concrete elevators, such as the Montreal Harbor Commissioners Elevator of 1908.[8] Despite these preventative measures, destruction by fire was frequently catastrophic. Upon completion in 1895 Buffalo's largest elevator--the Eastern Elevator--had required 8 million board feet of timber, yet within four years the elevator was lost to fire. The composite Husted Elevator with wooden bins, concrete floors, and steel framed cupola was destroyed in a 1913 fire that claimed thirty-two lives.

THE STEEL AND TILE ELEVATOR

During the last decade of the nineteenth century, as steel, tile and concrete structures became viable alternatives to the wooden elevator, the various objections to fireproof elevator construction were overcome. In 1861 a pioneering iron grain elevator was completed in Brooklyn, New York. Comprised of cylindrical bins of wrought-iron plate, 50' high and 12' in diameter, the elevator was supported on cast-iron basement columns. The entire structure was sheathed in masonry curtain walling. Some years later, the first elevator with steel bins was completed at Girard Point, Philadelphia.[9] High initial costs discouraged further development of this form for three decades.

The Plympton Elevator of 1868 pioneered fireproof construction in Buffalo. Of workhouse form, the composite brick and iron structure featured cylindrical bins with a monitor-roofed gallery. Like its early iron and steel counterparts, the Plympton Elevator appears to have been too costly to challenge the supremacy of the wooden elevator. It seems to have been operational for only twenty-five years and was apparently demolished in the early 1890s.[10]

By this time, however, several factors had combined to bring about the demise of timber as a viable material for use in port terminal elevators. Open hearth steel was becoming available at a price which permitted its economic application to grain storage, and ferro-concrete technology was being successfully applied to grain storage in Europe and Britain. These developments were taking place at a time of unprecedented increase in the price of timber.

The attitude of financial institutions also hastened the demise of the wooden elevator. Insurance companies, realizing that the new fireproof elevators offered them relief from fire loss claims, quoted attractive rates on fireproof structures. Relative insurance premiums for the contents were 13-28 cents per 1,000 bushels for fireproof construction and $1.50 to $3.00 per 1,000 bushels for wooden construction.[11] Insurance premiums on the structure were 2-1/2 to 3 percent for wood, and less than 1/2 percent for fireproof steel construction. Banks came to require no insurance protection upon advances made to financing the construction of fireproof elevators. Folwell (1898) pointed out that the entire capital cost of a steel elevator could be repaid within a few years by the saving in the insurance premium alone.

For the purposes of calculating depreciation, the wooden elevator was considered to have a life of 25 years, while that of the steel elevator was thought to be indefinite. Given a 4 percent depreciation on capital, and the requirement to set aside bank interest at 3-1/2 percent, Kennedy (1901) was able to claim that steel "is altogether the most suitable and economical material" for elevator construction. In his paper, Kennedy shows how the 4 percent depreciation cost reduced the comparative capital cost of construction of the steel elevator to little more than that of the wooden elevator. The 1 million-bushel wooden Export Elevator (1897) cost 13 cents per bushel the same year the steel Electric Elevator of similar capacity cost 15 cents per bushel. An average cost of 20 cents per bushel is given for steel construction at the turn of the century.[12]

Buffalo played a pioneering role in the revival and development of steel as a suitable, economical material for elevator construction. Practical operating experience with early steel elevators dismissed some of the misgivings about the suitability of steel and iron for grain storage. Principal amongst these was the belief that under certain atmospheric conditions condensation would occur within the tanks. It was found that the enclosure of the bins so as to prevent the free circulation of air in the interior practically eliminated this problem. Real objections to the material did exist; although noncombustible, it was not truly fireproof, and in the event of some external source of fire, damage could be extensive. The material's high thermal conductivity could induce overheating of stored grain during the summer months. The imprecise knowledge of the mechanical behavior of grain both at rest and in motion led to the construction of elevators liable to structural failure, particularly through "vacuum collapse" during grain draw-off.[13]

Buffalo's two pioneering steel elevators, the Electric and Great Northern of 1897, both used cylindrical bins with hemispherical bottoms. The bins of the Electric--possibly built to the patent of F. J. Weber--rise from hemispherical concrete dishes at grade, below which are conveyor tunnels.[14] Tie bars pass from the bin bottoms through the foundations to be made-up against concrete foundation anchor blocks. In this regard, the elevator shows a form resembling the tunnel-type concrete elevator, the Connecting Terminal Annex (1954), for example. The bins are exposed to the weather and were served from the adjoining workhouse by a minimal overhead gallery.

The Great Northern was a more complex structure with a bin configuration anticipating the utilization of space within the classic concrete elevator.[15] Small, self-contained cylindrical bins were placed between the main bins in an attempt to minimize lost storage capacity in the interspaces. The arrangement ensured that 80 percent of the available area was occupied by storage, a utilization of space only slightly less efficient than the 90 percent attained in the wood crib-binned elevator. The bins were raised on steel pillars supporting a steel ring girder, within which they rested.[16] These arrangements are visually similar to, though mechanically different from, those of the later generation of concrete elevators in which the bin hopper rests upon a concrete ring girder supported by radially arranged basement pillars. In order to provide for the storage of intermediate- sized shipments some of the main bins were subdivided horizontally, a feature incorporated into concrete elevators in the second decade of the twentieth century. The full cupola above the bins was supported by extensions to the basement pillars. The bins were enclosed within brick curtain walling to protect them from excess heating and weathering.[17]

The Great Eastern Elevator (1901), the Iron Elevator (1902), and the Monarch Elevator (1905) featured an increased application of concrete, particularly to basement structures. The Great Eastern Elevator pioneered the extensive use of reinforced concrete for basement structures with its 33" square basement pillars supporting a 36" thick bin slab and concrete hopper bottoms.[18] Similarly, the Iron Elevator used rows of bracketed concrete pillars to support reinforced concrete hopper slabs, which also provided the landings for the steel bins.[19] Similar arrangements are thought to have been employed in the Monarch elevators, which featured exterior basement walls composed of partial polygons, a form that was widely adopted in later all-concrete elevators, the Washburn Crosby complex (1909-26), for example.

Although, as in the Electric, the bins of the Great Eastern were free-standing cylindrical units, better utilization of space was obtained by arranging them in interlocking rows. The arrangements at the Monarch and Iron elevators were more innovative and demonstrated a spatial conformation that was to become widely adopted in later concrete elevators. The Monarch Elevator featured tangentially linked cylindrical main bins with interspace bins formed between, and shared walls in common with, four adjoining main bins.

The Iron Elevator used a more complex configuration of interlocking cylindrical main bins. The area between four main bins formed interspace bins proportionately smaller than those in the Monarch Elevator; however, quarter wall outerspace bins were added between exterior main bins. The elevator was built according to the MacDonald patent of September 17, 1900, in which the bins were arranged so that a standardized curved plate could be used throughout the structure. Three such plates were fastened to form a triangle, and the pre-fabricated triangles were assembled such that the interior of the units formed an interspace bin and the exterior formed one-sixth of a main bin.[20]

The Dakota Elevator of 1901 was of the full basement, full cupola type, resembling the Great Northern Elevator. Its bin arrangements appear to have combined the superior utilization of space inherent in the rectangular bin with the improved strength of the cylindrical form. Rectangular steel bins, arranged in a similar fashion to cribbed timber bins, were structurally very flexible. Shared bin walls of flat plate distorted under the uneven loading conditions between adjacent bins. If bracing were added across the bin to counter this tendency, it was likely to be torn from the plate under the increased pressures of grain draw-off.

The Dakota Elevator, probably built under the patent of Ballou and Shirley, featured straight side plates shared between bins but with curved end pieces. The straight side pieces were indented so that the contoured surface might increase their rigidity. An interspace bin was formed between the four curved end plates where four bins met. Outerspace bins were formed between exterior main bins by bridging the two curved end plates of adjoining main bins with an exterior flat plate. The application of flat exterior walls to form outerspaces between curved walls of small radius anticipated a similar practice in concrete construction, as in Husted (1907), Lake & Rail Northwest Annex (1930), and Meyer (1913).

Later steel additions to both the Monarch and Electric elevators reverted to the structural elements of the original Electric Elevator, though with larger bins. Buffalo's final elevator constructed with steel bins was erected in 1922 as part of the loading elevator at the Spencer Kellogg complex. It was built on a concrete basement supported by columns and consisted of four 2 x 2 spread cylindrical bins enclosing a single large interspace bin. The link walls were convex curved plates joining the bins at their closest points.

At the turn of the century the cost of a wood crib-binned elevator was 12 to 15 cents per bushel. The comparable figures of 15 cents per bushel for the Electric Elevator and 17 cents per bushel for the Great Northern Elevator were competitive, given their lower operational and depreciation costs.[21] By the turn of the century the cost of the average steel elevator appears to have been about 20 cents per bushel, a figure close to that required to build a concrete elevator some years later.[22] Although the dead load of a concrete elevator was considerably heavier than the same sized steel elevator and required proportionately stronger foundations, once the advantages of elevators with concrete bins had been accepted and weatherproof properties proven, the steel elevator's brief decade of supremacy was over.

During the first decade of the century, the application of ceramics to the problems of grain storage enjoyed a brief period of popularity. Tile bins introduced at the turn of the century were already considered obsolescent by 1913.[23] Only two or three elevator building companies held patent rights on tile bins, and they attempted to exclude others from the field. The Barnett Record Company held the rights to build the bins patented by E. V. Johnson as well those of its own design patent.[24]

The Moulton Witherspoon Company was another prominent builder of tile bins holding it own patent, as was the Preston Lancing Company. Tile bins were constructed in courses of plain and channel tiles. The channel tiles accepted horizontal tensile reinforcing bands later adopted in concrete bin construction. All walls were double leaved, with an outer skin of ceramic tile bonded to the inner wall that contained the steel bands. The tiles were laid in mortar using conventional construction techniques. The bin floor was comprised of a grid of I-beams filled in with hollow ceramic book tiles.

The early patents were for rectangular or cylindrical bins in which the interspaces were not used. Elevators built to these patents were of the tunnel type, with the bin walls rising directly from the foundations and discharging into a conveyor tunnel. By 1899 the Barnett Record Company was building tile elevators to a sophisticated design, the Johnson Record patent of that year having introduced the concept of the spread main bin, which was to be widely adopted in later concrete elevators. Interspace bins of considerable volume were created by the separation of the main bins and addition of connecting link walls. The link walls were formed by two shallow arched tile walls tied by a single central rod. These early patents also allowed for the raising of the bins on basement columns and the provision of tile hopper bottoms.

The tile bin was produced in a limited number of pre-fabricated sizes, and its application tended to be limited to those requiring large capacity bins. As in other systems employing the cylindrical bin, the elimination of wasted space became an important design issue. In comparison to the concrete elevator, the tile elevator's lighter weight reduced foundation requirements; however, the large number of mortared joints made it difficult to ensure an absolutely waterproof structure, and, like concrete tile, could only be worked on during frost free seasons.

Unlike steel elevators, tile structures were truly fireproof. The lower thermal conductivity and hollow form of the tiles provided a better insulated bin which was less likely to cause overheating of the grain.[25] Elevators with tiled bins were not popular in Buffalo, the 150,000 bushel Washburn Crosby "A" Elevator and the 100,000 bushel Maritime Milling Elevator being the only known representatives of the type. The Washburn Crosby Elevator was built by the Barnett Record Company to the earlier patents of E. V. Johnson, and featured cylindrical bins in tangential contact rising directly from the foundation slab. The Preston Lancing tile construction method was used at the Maritime Milling Elevator and consisted of four cylindrical bins placed at the corners of a structure featuring outerspace bins with convex quarter walling.[26]

The questions posed and problems solved during the era of the iron elevator were not without relevance to the development of the concrete elevator. It was during this period that the mind of the trained engineer was first applied to the design of the grain elevator. No longer constrained by a mode of construction in which the rectangular bin was clearly the best, or by the limitations of a material which dictated a maximum bin size of 15,000 bushels, the elevator engineer was free to experiment with various bin geometries.[27]

The wooden elevator had been drawn to dimensions and assembled according to longstanding empirically derived "truths." The advent of the formally schooled engineer into the field of elevator construction exposed an imperfect knowledge of the behavior of grain, both at rest and in motion. In order that steel elevators might be drawn to dimensions and proportioned safely and economically, a number of engineers addressed these problems experimentally. The understanding gained provided the engineering criteria by which all subsequent generations of grain elevators were designed.

Crucial to the design of safe and economic grain bins was the realization that grain behaved as a "semi-fluid" in which the pressure exerted on bin walls and bottoms was entirely different from that generated by a true fluid. Under static loads, the pressure exerted by grain at the base of the bin was found to be only a part of the pressure produced by a fluid of the same density. However, this pressure was transferred to the side walls of the bin as a result of grain arching generated by inter-granular friction. Under non-static conditions, particularly during grain draw-off, considerable pressure increases could occur on the side walls.

A quantitative understanding of the relationship between lateral and vertical pressures within bins was necessary to ensure their adequate yet economical design. Janssen (1895), Airy (1897), Jamieson (1900), Bovey (1901), Lufft (1902), and Pleissner (1902-05) all conducted tests to determine the distribution of static loads within bins. Although their discoveries differed in some details, the measure of agreement was sufficient to produce a general theory of grain pressures.[28] The lateral pressure in the bin was found to be less than the vertical pressure. The pressures were not directly proportional to the depth of filling, but depended also on the angle of internal friction of a particular grain, the coefficient of friction between the bin walls and the grain, and the ratio of the diameter of the bin walls to their height.

As a consequence, it was observed that the lateral and vertical pressures increased very little after a depth of 2-1/2 to 3 times the width or diameter of the bin had been exceeded. The ratio of horizontal to vertical pressures was found to be between 3/10 and 6/10, depending on the type of grain and its relative depth, with the ratio increasing towards the base of the grain column. Vertical bottom pressures were found to be least at the bin walls and greatest at the center of the bin.

Experiments with moving grain showed that, during draw-off through a centrally located spout, pressure increases of about 10 percent could be expected.[29] However, if draw-off took place through valves located at the side of a bin, lateral pressures would decrease on the wall close to the valve, but could increase by factors of 200 to 400 percent on the opposite wall. Given that excess pressures were not generated during draw-off, it was found that maximum lateral wall pressures occurred immediately after the filling of bins, and that these pressures were slightly greater if bins were filled rapidly.

THE CONCRETE ELEVATOR

The suitability of reinforced concrete for grain bin construction was first realized in Europe. Although it was difficult to make concrete absolutely waterproof under pressure, concrete could readily shed rainwater, and its low thermal conductivity reduced the chances of grain overheating in storage. The fireproof material provided smooth, crevice-free surfaces upon which dust was less likely to accumulate and which could be easily kept clean. Dust explosions could be more readily contained should they occur. Basements, and particularly the sub-surface boot tanks into which grain was spouted for elevation by the fixed legs, could be rendered totally watertight.

An extremely versatile material, concrete could be poured within reason to any bin configuration. When designed to withstand predicted loading conditions, it was strong and durable, requiring only an occasional coat of cement paint. Although design work could become quite complex, the erection process was speedy, and relatively few skilled men were needed. Most necessary materials, such as sand and gravel, could be obtained locally. The disadvantages of concrete construction were few; the great weight of the structure in comparison with either steel or tile dictated more substantial foundations, and concrete construction work could not be carried out during winter when frosts were likely to occur.[30]

The impetus towards the adoption of the concrete elevator in America was provided by F. H. Peavey. The Minneapolis grain dealer commissioned engineer C. F. Haglin to investigate the pioneering "ferro-concrete" (reinforced concrete) grain "silos" (bins) that had been constructed in Europe during the last decade of the nineteenth century. The Belgian Francois Hennebique had been particularly prominent in the application of his "rational," "monolithic" reinforced concrete system to the problems of grain storage.

The Weaver's Mill Granary (elevator) at Swansea, Wales, might be considered representative of contemporary European practice. The building was of rectangular plan and contained 100, 7'-6" square bins. The 66' deep bins were supported on columns that provided a full basement. The limited degree of bulk handling in Europe required spacious basements for the sacking of materials for shipment. The exterior bin walls were of pillar and panel form, and their thickness varied from 12" at the base to 4" at the bin floor. The interior divisions were only 3" thick. Smooth round reinforcing rods were linked by stirrups of flat bar. The horizontal rods were trussed about the piers so that the bin walls acted as beams. The building was constructed in discrete

3' lifts using conventional timber form work. Such form work had to be "struck" (dismantled) when a lift was set and rebuilt for the pouring of the next lift. Full scaffolding was necessary for form carpenters, steel erectors and concrete pourers.[31]

Haglin's solution to the problems of grain storage differed radically in conception and construction from the European model. Like his contemporaries in the field of iron and tile elevator construction, Haglin recognized the inherent structural advantage of the cylindrical bin, particularly for the large volume storage required in the bulk American grain trade. As no personnel handling was required below the bins, these could rise directly from the foundations, with the transfer conveyors housed in sub-surface tunnels. Haglin devised an even more radical system of form work which did not have to be "struck" after every lift and dispensed with the need for full scaffolding. His forms were comprised of two circular rings separated by yokes. The concrete was poured between the two rings, and, once set, jacks moved it upwards for the next lift.

In 1899, Haglin designed and erected a single cylindrical bin 124' high and 20' in diameter with walls graduated in thickness from 12" at the base to 5" at the top. Following the successful completion and testing of the experimental bin, work commenced on America's first reinforced concrete grain elevator in 1900. The Peavey Elevator at Duluth was engineered by Haglin and constructed using his patented forms. The elevator consisted of thirty bins 33'-6" in diameter rising directly from the foundation slab to a height of 104'. The thickness of the wall decreased from 12" at the base to 6' at the top, and was reinforced with 1-1/2" hoops with courses varying from 11" at the base to 18" at the top. The bins were not in tangential contact, but connected by 6' link walls to create large interspace bins.

Soon after the elevator's opening, one of the interspace bins failed. As some of the adjoining main bins were empty, the main bin wall acted as an arch. Adequate abutments had to be added to retain the wall. The bending moments upon the main bin walls were increased greatly by the long link walls. Such ambitious engineering was to prejudice the reputation of reinforced concrete as a suitable material for elevators.[32]

The early years of the century saw a rapid increase in the number of tile elevators. These were constructed under closely held patents so that elevator builders unable to acquire such rights, and wishing to supply the increasing demand for fireproof elevators, were obliged to investigate the use of reinforced concrete despite the material's poor reputation following the failure at Duluth. The prominent steel elevator builders James Stewart Company and James McDonald Company both found themselves in such a position. The two companies were responsible for the expansion of Haglin's concepts to a stage of development such that by the close of the first decade of the century the fundamentals of American elevator building practice had been established.

Haglin's forms could be raised continuously on "jacking rods" that were incorporated into the vertical reinforcing system of the bin walls. Concrete could be added continuously as the forms were raised. Such "slip form" work permitted construction to proceed at an unprecedented rate; however, the graduation of wall thickness with height became an uneconomic proposition. Both companies adopted systems of reinforcement similar to Haglin's, featuring discrete horizontal tank bands tied to verticals. The Metcalf Company appears to have made some early experiments with a horizontal system in which the rods were linked to form a continuous spiral. Chicago's Santa Fe Elevator, built in 1907, corresponded to this pattern. The pioneering companies were so successful that by 1910 all those previously specializing in the construction of patent tile elevators were also involved in concrete construction. The earliest to effect this transfer was the Barnett Record Company with its construction of the concrete Canadian Pacific (King) Elevator, Port Arthur, in 1903.

The builders of concrete elevators, anxious to retain the benefits of cylindrical bins without sacrificing versatility or the efficient use of space, adopted the new forms of bin arrangements developed during the evolution of the steel and tile elevator. With few exceptions, all used cylindrical bins in either interlocking or non-interlocking rows with tangential or link wall connections and interspace bins. Concrete elevators also featured other innovations introduced by the designers of steel and tile elevators, including the outerspace bin with either curved or straight outer walls and the horizontal subdivision of cylindrical bins.

The adoption of concrete as a building medium for grain elevators provided designers with new freedom in their choice of size, shape and arrangement of grain bins. The choice of arrangements within any one elevator was determined by factors such as the operational requirements of the promoter, the constraints of the site, the optimal use of materials and the limitations of technology. The principal dimensions of Buffalo elevators varied considerably. Bin diameters ranged from 15-19' at the Lake & Rail Northwest Annex (1930) and the Husted elevators (1908) to 38'-1-1/2" at the Standard Annex (1941). Bin heights varied from 70' at the Dellwood "B" Elevator (1916) to 150' at the Lake & Rail Northwest Annex (1930), with the exception of the 160' free-standing bins built at the Spencer Kellogg site in 1912 and 1936. The cylindrical form was almost universal; the Ralston Purina "B"

Elevator (1917) and Allied Elevator (1946) were the only Buffalo elevators known to have used rectangular bins exclusively.

THE EVOLUTION OF THE CYLINDRICAL CONCRETE BIN

The concrete elevator came to be associated with parallel rows of tall cylindrical bins, a form that became preeminent for several reasons. The cylindrical form provided the maximum storage volume per area of bin wall for an individual bin standing in isolation. For example, to provide 201 square feet of storage, a cylinder of 16' diameter had 50'-3" of walling, a hexagon 52'-9" of walling, and a square 56'-8" of walling. However, although containing more material, the square bin only occupied an area of ground 14'-2" x 14'-2". When individual bins were grouped together, the situation became more complex. The rectangular/square bin used available space more efficiently than the circular bin. The addition of inter- and outerspace bins between the main cylinders improved the utilization of space. The larger the circular bin, the more closely it approached the spatial efficiency of the rectangular bin.[33]

Although lateral stresses exerted on the sides of a circular bin are uniform, any other form generates unevenly stressed bin walls. In order to balance the stresses, such walls are designed as beams, which requires bending twice the number of reinforcing bars to more complex shapes than would be necessary in a cylindrical bin of similar volume. In balancing the equation of volume of storage to the reinforcing requirements, the cylindrical bin was found to be more economical at diameters in excess of 12' to 15', while the rectangular form was favored if the diameter fell below this point.[34] In addition to higher materials costs, the construction of square bins was also more difficult to standardize. The placing of increased volumes of materials in more complex configurations resulted in higher labor and form costs when building square bins.[35]

The proportioning of the bin walls, and the size and distribution of the reinforcing within, reflected the stresses predicted by turn-of-the-century theorists. Janssen's formula was the most popular, but all theories recognized certain fundamental characteristics of grain stored in deep bins. Simply stated, they observed a fundamental change in the behavior of grain at a depth of about three diameters. At this point the mass of grain arches and, while below it behaves almost as a solid, above this level it functions as a semi-fluid.

Owing to the arching effect, the addition of grain above this point does not materially add to the load carried on the bin bottom; the additional load is carried almost entirely by the bin wall. The lateral pressures vary exponentially, rising steeply in the lower part of the wall and falling rapidly after the bin height has exceeded three diameters. The stresses generated are resolved into forces requiring concrete of sufficient strength and quantity to resist the crushing effects of compression, and stresses requiring steel reinforcing able to withstand the pull of tension.

The bin wall had to be sufficiently thick to bear the compression of the structure and the vertical load brought upon the wall by the lateral grain pressure. The former varied according to the weight of the structure above, and the latter by the relationship of the bin's depth to its width. The weight of the structure is greatest at the base of the bin walls, while the greatest transfer of lateral stress occurs in the lowest part of the wall up to the point where its height is equivalent to three diameters. The compressive stresses progressively increase toward the base of the bin wall.[36]

In Haglin's early designs, wall thickness was altered to reflect the changing compressive stresses in the walls. When walls were still constructed in discrete lifts, it was relatively simple to alter the distance between inner and outer forms with an adjustable yoke. The advent of slip forming made such adjustments more difficult. The forms had to remain a set distance apart and any adjustment in wall thickness was accomplished by the insertion of fillers. Few examples of this construction exist in Buffalo. The Superior "C" Elevator (1925) has 12" bin walls for the first 7'-6", the remaining wall being 9" thick. The Saskatchewan Elevator (1925) has 18" walls for the first 12' and 7" thereafter.

Because the insertion of fillers complicated slip forming procedures, walls were usually of uniform thickness, proportioned according to the maximum compressive stresses predicted to occur at the bottom of the bin wall. The fine tuning of wall thicknesses by the James Stewart Company is demonstrated in the Washburn-Crosby "B" and "C1" elevators, both built in 1909. The "B" Elevator has a diameter of 19' and walls of 8". The 31' diameter bins and 9" walls of the "C1" Elevator reflect the larger lateral forces transferred through them.

The average thickness of bin walls in Buffalo elevators is 8", the thickest being 9" and the thinnest 6". Although the bin walls of the Lake & Rail Elevator Northwest Annex (1930) were built to this minimum dimension, the 150' x 15' bins are exceptionally tall and narrow, confining much of the transferred lateral load to the first 40' of wall. The Connecting Terminal Annex (1954) also has 6" walls; however, its proportions differ little from those earlier elevators with 8" walls. It was also proportioned according to Janssen's formula, suggesting that earlier designers added an additional margin of safety in dimensioning walls.

Wall thicknesses were seldom altered to reflect the changing compressive forces in the bin wall, but the proportions of the concrete mix could be altered according to pressure differences. Until the 1920s, all the bin walls in Buffalo elevators were constructed using a 1:2:4 (cement/sand/gravel) mix which produced a wall able to resist 2,500 psi of compression. During that decade, the strength of the lower sections of wall was increased by enriching the mix. Marine "A" Elevator (1925) had a mix of 1:1:2 for the first 13' and a 1:2:4 mix above 21,' while the Lake & Rail Elevator (1927) had a 1:1-1/2:3 mix for the first 27' and a 1:2:4 mix thereafter. The Eastern States Elevator (1934) used a 1:1-1/2:3 mix for the first 29' and a standard 1:2:4 mix thereafter. By employing such methods, the bearing pressure of the concrete could be increased to 3,000 psi at the base of the bin wall.

In addition to bearing compressive loads, the bin walls had to be able to withstand the tensile loads imposed by the lateral grain pressures, by thermal expansion and contraction, and by the pressures of filling and emptying. These stresses could not be born by the concrete alone and required steel reinforcement. The basic reinforcement system consisted of horizontal tank bands designed to counter the lateral grain pressures. The bands were wired to verticals designed to distribute the unequal stresses caused by both thermal effects and loading/unloading. The jacking rods formed an integral part of the vertical reinforcement system.[37]

The distribution of lateral pressures was calculated using Jannsen's formula, which takes into account the ratio of bin depth to diameter, bin surface area and grain weight. This information was resolved into a series of characteristic curves from which lateral pressures for particular depths and heights could be read directly. When horizontal reinforcing of a particular tensile strength was specified, the cross-sectional area of the grade of steel required to balance the lateral pressures at a particular depth could be calculated.

Tensile strengths of the horizontal steel rose from around 15,000 psi in the earlier elevators, Concrete-Central (1915) for example, to 21,000 psi in the Electric Elevator (1941). If the lateral pressure was 330 psi at a certain depth, then .02 square inch of 16,000 psi steel would be required to balance the tensile pressure on that square inch of wall. As the installation of such a small amount of steel was impractical, larger units of wall were considered. One possibility was to divide the wall into equal units within which one horizontal band would be placed. Each band was known as a course, and 12" was commonly chosen as a course interval.[38] Over such a 12" interval assumed to be at 330 psi, sufficient steel was necessary to balance 3,960 psi. Specifying 16,000 psi steel per bar with a sectional area of 1/4 square inch would provide 4,000 psi, thus balancing the lateral grain pressure over the 12" interval. Such a sectional area could be provided by a 1/2" square bar, a flat bar of 1" x 1/4" or a round rod.

The reinforcing pattern generated by this method produced horizontal bands dimensioned to the changing lateral pressure, but placed at a constant course interval. Such a system found favor with most elevator builders--Barnett Record, James Stewart and Monarch Engineering, among others--during the first two decades of elevator construction. The former company's Canadian Pacific (King) Elevator, Port Arthur, of 1903, had horizontal bands arranged at 12" intervals and ranging from 2" x 1/4" at the base through five bar graduations to 1" x 3/16" at the top of the bins.[39]

For larger bins, the James Stewart Company appears to have introduced additional variables into its system. The company apparently varied the tensile strength of the horizontal bands according to their height in the bins. Bands were placed at fixed course intervals, but above a certain height the bar size increased. This change probably occurred where lower tensile strength material was employed. By this method, the area of steel within any one interval in the upper parts of the bin was greater than would otherwise have been the case. As a consequence, the bending moments within the concrete between the bands was reduced, which in turn reduced the amount of vertical steel required.

An alternative method of generating the correct amount of horizontal reinforcing was to maintain a constant size of reinforcing, but adjust the course interval to balance the lateral pressure at a particular depth.[40] For example, if 3/8" diameter rods of 16,000 psi strength steel were specified, then each rod would be able to bear 1,770 psi of tension. At that point in the bin wall where the lateral pressure was predicted to be 330 psi, the rods would have to be spacedin courses at 5-1/4" intervals. If 1/2" diameter rods were specified, then they could be spaced in 9-1/2" courses for the same lateral pressure, and so forth. In practice, horizontal reinforcing came to be deployed through a combination of both techniques, resulting in a system of graduated bars at variable course intervals. The Metcalf Company appears to have made an early experiment with a spiral horizontal system; rather than forming individual tank bands, the horizontals were connected by hooked links to form a continuous spiral, the pitch of which varied from 7" at the base to 12" at the top. The Santa Fe Elevator of Chicago (1906) is the only known example of this form of construction.[41]

Sources show that Janssen's formula was used to calculate horizontal reinforcing in Buffalo elevators from 1908 to 1954. The means by which reinforcing was deployed to satisfy Janssen's formula followed definite trends. Until the mid-1920s, elevators almost universally used smooth flat bars arranged with their long axes vertically. The bar sizes were graduated, diminishing with height, and arranged at fixed course intervals. An exception to this trend was the Dellwood "B" Elevator (1915), which used graduated smooth square bars at variable course intervals. The Dellwood is the only known example in Buffalo of both the variable coursing of non-round bars and the use of square reinforcing bars in the main bin.

The James Stewart Company's Washburn Crosby "C1" (1909) and Washburn Crosby "C2" (1913) also feature horizontal bands comprising rectangular bars placed at fixed course intervals; however the graduation of bar size is stepped at approximately two-thirds height. The increase of bar size at 74' and 85' reflects the increased cross sectional area of lower tensile strength steel required to balance the tensile stresses on the bin wall. Like other earlier designs, both elevators use a relatively large number of bar sizes to achieve a fine graduation of horizontals. In the case of the "C1" Elevator, the lower part of the bin wall has three graduations of bar sizes and the upper part has two graduations. The lower part of the "C2" Elevator wall has four bar graduations, while the upper part is graduated as in the "C1" Elevator.

From the mid-1920s, round bars were used exclusively as horizontal reinforcing in all Buffalo elevators. Superior "B" Elevator (1923) was the last built with flat bar. Round bar could simply be substituted for flat bar in graduated sizes at fixed course intervals. Examples of this type include the Eastern States (1934 and 1946), GLF "A" (1941) and Connecting Terminal Annex (1954). There are no known early (mid-1920s) round bar examples of this type of arrangement. Alternatively, standard sized round rod could be coursed at progressively wider intervals with height. The Saskatchewan Elevator (1925) is the best example of this type, with 1/2" rods coursed successively at 5-1/2", 6", 7", 8", 10" and 12" intervals.

The Lake & Rail Northwest Annex (1930) employs a similar method of reinforcing, though with fewer progressions in the coursing. No post-1920s examples of this pattern of reinforcing occur. The majority of elevators built from the mid-1920s onward combine elements of bar graduation and coursing variation. Some feature a system in which rod graduation is the main variable. Marine "A" (1925), Superior "C" (1925) and Standard Mainhouse (1928) employ only one course change. The abruptness and scale of the change is such that the lower rods are smaller than the upper rods. Perot Annex (1933) employs only one course change and the usual progressive graduation of rods with height. The alternative system employs fewer changes in rod size but more frequent changes in course intervals. Lake & Rail (1927-29) was built by this method, which reached a peak of complexity in the main bin walls of the Standard Annex (1941).

The Hettelsetter-built Lake & Rail complex (1927-30) demonstrates further subtlety in the proportioning of horizontal steel in order to balance the tensile stresses in the bin wall. This company appears to have favored a variation upon the previously mentioned method of reinforcing. Although it employed the typical horizontal bands placed at varying course intervals, Hettelsetter was apparently unique in using bands of both round and square section steel. By changing from square bar to round rod of the same dimension, a particular coursing interval could be maintained to a greater height in the structure, the cross sectional area of the rod being less than that of the bar. This method simplified construction by reducing the number of course changes and bar graduations.

The change from flat to round horizontal reinforcing in the 1920s apparently coincided with a change from smooth to deformed bars, that is, those with an exterior texture. The patterning had to be rolled onto the rods during manufacture; no rod with a texture produced by twisting was permitted. A tensile strength of 15,000 psi was specified for the flat bar in Concrete-Central (1915). Higher tensile strengths were necessary when horizontals were of round rod. Typically 16,000 to 18,000 psi was specified, rising to 21,000 psi in the Electric Annex (1941). Although re-rolled rail was usually employed in the earlier elevators, the popularity of this material appears to have declined during the 1920s. Following its use in the Marine "A" (1925) and Superior "C" (1925) elevators, all Buffalo elevators appear to have employed horizontals of new billet, as in GLF "C" (1936), GLF "A" 1941) and Eastern States (1934 and 1946).

The early popularity of the horizontal band of flat steel placed in fixed courses was twofold. As the steel was proportioned to deal with a load averaged over 12" increments of wall, it was structurally desirable to distribute as much steel as possible perpendicular to the lateral pressure. The flat bar arranged vertically provided such an arrangement.

The use of flats in fixed courses was also based on practical considerations of construction. Steel placement was simplified if all courses were equal, and it was easier to ensure that steel was being placed correctly. The increased probability that the horizontal steel was in the correct place across the entire lift of forms aided the levelling of the forms as jacking proceeded. There were, however, disadvantages to this system; vertical steel requirements were increased for two reasons. The bending moments generated between reinforcing bands placed at the relatively large interval of 12" was greater than in other reinforcing systems featuring graduated coursing, and the relatively flexible rectangular bars had to be held firmly in place during concreting operations.

The bending moments between bands could be reduced by using thin, elongated bars which maximized the vertical extent of tensile steel. The problems of the flexibility could be reduced by the use of square section bars; however, bending moments between such bands were increased as the tensile steel was distributed less evenly through the height of the bin wall.

Early practice calculating bar dimensions dictated the division of walls into more units than was the case later in the century. The American Elevator (1906) and the Kellogg Elevator (1910) are the best examples and show the bar size diminishing upward through a succession of bars showing small changes in dimension. The American Elevator used eight different bar sizes, and the Kellogg Elevator five. The Washburn Crosby elevators "B," "C1" and "C2" show a similar though less pronounced trend.

By the second decade of the century, this rather precise dimensioning had given way to a simpler formula which reduced the number of bar sizes used but required unnecessary reinforcing steel. This standardization of bar sizes only occurred in the lower part of the wall, where lateral pressures rose most rapidly, and the relative differences between successive graduated bars were smallest. Both the Concrete-Central (1915) and Dellwood "B" (1915) elevators demonstrate this change. While the former has three sizes of horizontal reinforcing, the introduction of variable coursing reduces that number to only two in the Dellwood "B".

The introduction of round horizontals coincided with changes in the procedure for calculating the distribution of vertical steel. Reinforcing was placed more closely at varied course intervals to better balance the lateral pressures in any part of the bin wall. Thus, the bending moments generated between bands diminished, reducing the vertical steel requirements. The introduction of this technique made it less necessary to distribute the steel vertically through a standard 12" course and permitted the application of a single size of bar in the horizontal reinforcing system, as in Saskatchewan (1925/26), which uses 1/2" rods.

However, the complication of varying the courses by small amounts at frequent intervals appears to have led to a combined technique in which larger and less frequent changes of course interval were made in combination with some graduation of the rods. Toward the end of the era of elevator construction, the simpler technique of earlier years appears to have been favored. Eastern States (1934 and 1946), GLF "A" (1941) and Connecting Terminal Annex (1954) feature graduated rods at fixed course intervals, though round rods rather than flat bars are used.

The location of the horizontals with respect to the inner and outer bin walls followed a simpler trend. As time passed, the bin reinforcing tended to be placed closer to the outside of the bin wall. In the Kellogg Elevator (1910) the outside of the horizontals are some 5-1/2" from the outer surface of the bin wall. The horizontal bars in the Washburn Crosby "C2" Elevator (1913) are located in the center of the bin walls, their outer surface 4" from the outside wall. The same pattern was followed in Superior "A" and "B" elevators (1915 and 1923) and Concrete-Central Elevator (1915-17). The thinner walls in these elevators caused the outer surface of the flats to be 3-1/2" from the outside wall surface.

The introduction of round horizontal reinforcing was apparently accompanied by a relocation of the wall reinforcing closer to the outer surface of the bin. In both Marine "A" (1925) and Superior "C" (1925) elevators, the outer surface of the horizontals is only 1-1/2" from the surface of the outer wall, while in Saskatchewan (1925-26), Lake & Rail (1927-29) and GLF "A" (1941) the equivalent figure is 2-1/2". It was assumed that the closer the horizontal steel to the outside of the bin wall, the better it would resist the tensile stresses from within the bin. With the exception of the Connecting Terminal Annex (1954), the horizontals are wired to the outside of the verticals. The reason for the reversal of this practice in the Connecting Terminal Annex is unknown. Horizontal thermal cracking in the exterior bin walls could be minimized by designing the horizontals of the exterior walls to a lower tensile stress value than those in the interior walls. However, the specification of steel for exterior and interior bin walling does not appear to vary in any Buffalo elevator.

Although precise calculation was fundamental to the successful deployment of horizontal reinforcement, the arrangement of verticals was less critical. Vertical steel was necessary to keep the horizontal bands in the correct location until the concrete had set. Considerable internal stresses could develop in walls where distortion of the reinforcing geometry had occurred. A vertical reinforcing system was also necessary to prevent horizontal cracks from developing through thermal expansion and contraction and shrinkage during curing. Verticals were required to transfer the local wall stresses that developed during the loading and unloading of bins. A certain proportion of verticals was arranged to act as vertical columns by which the forms could be raised. These "jacking rods" also acted as an integral part of the reinforcing system.[42]

During the early years of elevator construction, the distribution of verticals corresponded to the pattern advised by Milo Ketchum in Walls, Bins and Grain Elevators (1907). Following a mathematical consideration of the reinforcing requirements, Ketchum considers that for the purposes of reinforcing, stresses are minimal when 1/2" bars are spaced at 12" to 18" intervals in grain bins of ordinary size. The Kellogg Elevator (1910) has square verticals on 18" centers around the circumference of the bin, and the American Elevator (1906) has 1/2" square verticals on 34" centers. The Wheeler Elevator (1909) employs verticals of unknown size on 36" centers.

In both the American and Perot elevators, an external timber frame was used to raise the forms, and none of the verticals were used as jacking rods. An unknown number of these square verticals were used as jacking rods to raise the forms in the Wheeler and Kellogg elevators. The Washburn-Crosby "B" and "C1" elevators (1909) show the evolution of a more sophisticated approach in the placing of verticals. Jacking rods were located selectively at either end of the tangential contact walls where form binding stresses were likely to be largest, particularly in early rigid lifts. Ordinary square verticals on 5'-6" centers were placed only in those parts of the wall where no tangential thickening occurred. These arrangements concentrated lifting forces about the tangential contacts, leaving up to 15' of the bin wall where jacking rods were absent.

In 1915, the date of construction of the Concrete-Central "A" Elevator, jacking rods were positioned according to rational principles that were to remain valid throughout the era of elevator construction in Buffalo. By this date, early problems with certain mortars bonding to the forms had been solved, the 4' deep form had become standardized, and more flexible lifts had been developed.[43] Given these improvements, it was found that each jack could pull between 60 to 70 square feet of forms, representing an 8' interval between rods.[44] The jacking rods in the Concrete-Central Elevator were spaced equidistantly on 8' centers and coincided with the intersection of link and quarter walls. Intermediate square verticals were placed between each jacking rod to give a vertical every 4'.

With the exception of Marine "A" (1925), all elevators built after this date had jacking rods positioned equidistantly at about 8' intervals around the circumference of the bin wall. The Standard (1928) and Standard Annex (1941) used 8' intervals, the Saskatchewan (1925) 6', and the Connecting Terminal Annex (1954) 6'-6". In the Lake & Rail (1927) and Superior C (1925), the separation was greater, measuring 9' and 9'-6" respectively. Marine "A" was an exception, with jacking rods at an average interval of 12'-6".

During the 1920s, the function and deployment of ordinary (non-jacking rod) verticals began to be reappraised. The change in horizontal reinforcing from relatively flexible flat bars to more rigid round rods reduced the number of verticals required to hold the structure rigid while the concrete set. The introduction of round horizontals in varying course intervals produced a more even distribution of steel within the bin walls. The reduced moments generated between horizontals now placed at diminished intervals permitted a reduction in the vertical steel required to carry this load.

At the same time, the forces most likely to produce horizontal cracking were confined almost exclusively to the exterior walls, where thermal and freeze thaw effects were concentrated. From this date ordinary verticals tended to be deployed only in the exterior walls, leaving the jacking rods to deal with vertically acting tensile stresses in the interior walls. Marine "A" (1925) and Lake & Rail (1927-29) were the first Buffalo elevators to show this development. Marine "A" had ordinary verticals in both interior and exterior walls. Those in the exterior wall gave a spacing between verticals of 18", while the comparable figure for the interior walls was 4'.

Lake & Rail (1927) had no ordinary verticals in the interior walls, but verticals were positioned in the exterior walls at a 2" interval. Likewise, Standard Annex (1941) dispensed with ordinary verticals in the interior walls, but added a vertical every 18" in the exterior walls. GLF "A" (1941) retained ordinary verticals in the interior walls to give a spacing of 3'-10" and 1'-10" in interior and exterior walls respectively. Similarly, Connecting Terminal Annex (1954) retained ordinary interior wall verticals at 3' intervals, with 2'-3" in the exterior walls. However, unlike the other examples, the closer spacing of verticals extended through the tangential contact walls, the design having been modified to deal with the additional vertical tensile loads that occur in the tunnel style of elevator. The above trends were not universally adopted; the Standard Elevator (1928) and Eastern States elevators (1934 and 1946) retained an equal distribution of verticals around the circumference of the bin wall.

In the earlier elevators ordinary verticals were square, lugged bars of approximately 1/2". The transition to round horizontal reinforcing during the 1920s was paralleled by the adoption of approximately 1/2" deformed round rod as the standard material for verticals. Round vertical rods were usually of intermediate grade new billet, though this could be rerolled rail as in Marine "A" or hard grade new billet as at GLF "A". Jacking rods were almost universally of 1" diameter, new billet, hard grade steel.

The concept of the subdivision of the main bin may have originated in the construction of the cylindrical concrete marine tower at Washburn Crosby "C" Elevator (1912). The tower was subdivided both vertically and horizontally with concert walling. The first horizontally divided bin appears to have been in the Connecting Terminal Mainhouse (1914).

Subsequently, sophisticated subdivision occurred to create smaller bins and machinery spaces within whole bins. Both the Standard Mainhouse (1928) and Marine "A" (1925) accommodated cleaning machinery in the center of bins, with cleaner feed and receiver bins above and below. In the latter case, the bins were divided radially into four segmental bins and one central square bin. In such horizontally divided systems, the upper and lower bins were treated as two separate structures for the calculation of horizontal reinforcing, as the entire top bin load was transferred compressively through the lower bin wall. Both Saskatchewan (1925/6) and Lake & Rail (1927/28/29) subdivided bins vertically, half the cylinder being used for stairways and personnel elevators.

The cylindrical bin made little impact upon the European scene until the 1920s. The first application of the cylindrical bin appears to have been in 1907 at Dunston on Tyne (Newcastle); these were double rows of bins in tangential contact with interspaces and measured 45' in diameter and 72' in height. The wall thickness varied from 9" at the base to 6" at the top. The first bins built to the classic American pattern were at Silverton (London Docks) in 1908 and consisted of a nest of tangentially linked cylinders with both inter- and outerspace bins. At this early date, the trend towards thinner walled cylindrical bins had already been established in Europe, the 20' x 80' bins having a wall thickness of only 6".

The cylindrical bin was more widely adopted upon the introduction of slip forming methods. Despite the greater convenience of the cylindrical form when slip forming, substantial numbers of rectangular-binned elevators were constructed in the inter-war years using such methods. The first record of slip forming is at the London Dock Nut Silos, built in 1917 to the classic American plan. Although of 32' diameter and 88' high, the walls were only 4" thick.

Subsequent trends in wall thickness appear to have followed two paths determined by construction methods. Where shifting panel methods were applied, wall thicknesses of 4" were common. In proportioning such walls, European engineers employed a formula other than Jannsen's. Possibly as a result of the extra rigidity required to support the jacking rods while construction was still under way and the concrete below the forms still "green" (not fully cured), the trend toward very thin-walled slip formed structure was reversed. The Royal Victoria Silos (London Docks), with diameters of 16', heights of 88' and wall thicknesses of 6-1/2", represents the new construction method and corresponds to similarly dimensioned bins in America.

THE EVOLUTION OF THE RECTANGULAR CONCRETE BIN

Examples of elevators with deep rectangular or square bins are extremely rare in Buffalo. The Standard Mills Elevator (Keystone, 1913), the Ralston Purina "B" Elevator (1917), the Kriener "B" Elevator (1936) and the Allied Elevator (1946) are the only Buffalo elevators known to use rectangular bins exclusively. Elsewhere, this form was confined to workhouse and cleaning and drying functions--the drier and cleaner bins at Superior "A" (1915), the Lake & Rail workhouse (1927), the Standard drier house (1928), a single row between elevator and mill at the Lake & Rail Annex, and the GLF "A" east workhouse (1941).

Although uncommon in elevator applications, the rectangular/square form is virtually universal in mill and processing plants, where it provides the most economical configuration for the storage of relatively small lots of feed stock and processed materials. Standard Mills (Keystone, 1913), Pillsbury Mills, part of the Great Northern Elevator complex, (1922), and GLF (1929, 1961) feature rectangular bins incorporated within the structure of the mill. Although Buffalo's largest rectangular bins are in the Kriener "B" Elevator (1936) and measure approximately 14' x 12', those in the Allied Mills Elevator (1946) are the deepest at 93' and approximately 11' square. The smallest rectangular bins appear to be those in the pellet mill at GLF (1961).

A rectangular bin configuration has been shown to be the most efficient in land use. However, as bin surface area increases, any such economy is soon outweighed by the materials required to resolve the stresses in the rectangular/square bin. Unlike a cylindrical bin, the levels of stress on the bin wall differ at any given height; the moments increase according to the distance from the bin wall. Furthermore, as the corner of the bin is approached, a reversal of the bending moments in the bin wall is possible.

Thus, the bin walls are designed to act as beams, with the bending moments transmitted to vertical pillaring at the corners of the bin. As the moments increase exponentially, relatively small increases in bin surface area are accompanied by considerable increases in wall thickness and the addition of reinforcing steel. Elevator engineers considered the rectangular/square bin the most economical arrangement when bin wall lengths did not exceed 12' to 15', the cylindrical bin rapidly becoming the better choice as diameters rose above 15'.

The reinforcing within rectangular bins is most efficient if the horizontals are trussed in the manner of reinforced concrete beams. As Hennebique's use of trussed horizontals in the last decade of the nineteenth century illustrates, such structural arrangement was appreciated early in the history of European elevator construction.[45] By adopting such a system, engineers matched the distribution of reinforcing with the tensile stresses within the wall and minimized material requirements. However, as such an arrangement complicated the construction process, it was more usual to use greater amounts of steel in single or double straight bars that satisfied the maximum tensile stresses, but considerably over-compensated in areas where tensile stresses decreased.

Further sophistication in the rectangular/square bin form could be introduced by progressively thickening the bin walls towards the corners, producing a wall with broad, elliptically shaped faces. Such an arrangement was used in Hennebique designs beginning in the early twentieth century. Despite its potential savings in concrete, this device was seldom employed in America, although the Canadian engineer J. A. Jamieson devised a square bin with elliptical walls, and elliptical rather than trussed horizontals, during the first decade of the twentieth century.[46]

Given the few elevators with rectangular/square bins built in Buffalo and the lack of original documentation, it is difficult to account for the evolution of the form. The A. E. Baxter Engineering Company appears to have been the principal proponent of elevators with rectangular/square bins, although both the Monarch Engineering and James Stewart companies were responsible for examples in Buffalo.

A. E. Baxter constructed both the first and last such elevators in Buffalo--the eight bins of the Standard Milling Elevator and those of the GLF Mill (1961). The company also commissioned the design of the Ralston Purina "B" Elevator (c. 1917), the rectangular bins in the Standard Elevator (1928) and the GLF "A" Elevator (1941), and the eighty rectangular bins in the GLF Mill and drier house (1929). The Monarch Company was responsible for the second set of rectangular bins constructed in Buffalo--the cleaner and drier houses at Superior "A" (1915) and Buffalo's largest representative of the type, the Kriener "B" Elevator (1936).

It is unclear whether any trussed and/or elliptically walled elevators with rectangular/square bins were built in Buffalo. All work designed by the A. E. Baxter Company featured straight horizontals, usually arranged as two rows of reinforcing close to the edges of the wall. Each row of horizontals was tied to its own row of verticals. This arrangement tended to be standardized for all walls irrespective of whether they were exterior walls, which only received tensile loads in one direction, or interior walls shared between two bins, which could receive tensile loads on either face according to the loading conditions in adjacent bins. Such conservative designs characterized most non-cylindrical bins designed by A. E. Baxter.

For very small bins with thin walls, such as those in the GLF Pellet Mill, a single row of reinforcing in the center of the wall was practical and provided adequate concrete cover. All examples of square/rectangular bins in Buffalo appear to have been slip formed. Where bins were given two rows of reinforcing, the jacking rods formed no part of this system, being arranged centrally within the wall as independent units.

The non-cylindrical bins in the east workhouse of GLF "A" (1941) may be considered representative of this slip formed type. The bins are 92' deep and arranged in a 4 x 5 configuration. The outer rows of four are comprised of 14'-6" x 9'-6" rectangular bins, while the inner three rows of four are 9'-6" x 9'-6" square bins. However, only three of the rectangular spaces are designed for grain storage, the remainder accommodating elevator legs, personnel elevators and stairways. The entire structure was raised from the basement slab by slip forming. The bins are raised on a central row of longitudinal pillars and supported on three sides by the straight exterior walls, while that side abutting the main storage is supported by substantial pilasters incorporated into the cylindrical basement bin walls. The full basement of 16'-2" provides support for a 10" thick bin slab with slab hoppering above.

Both interior and exterior bin walls are 8" thick. At the intersection of the exterior bin wall with every transverse interior bin wall and every other longitudinal interior bin wall, the external wall thickens to 12" or 15" to form an external pilaster 36" wide. This pilaster extends from the basement slab to the full height of the workhouse. The structural elements of pilaster and bin wall form, respectively, the piers and panels that are often characteristic of the elevator with rectangular bins. Internally, the corners of all bins thicken to form triangular fillets. The bins that intersect at pilasters or above the basement columns have the largest fillets. The combination of four fillets at the intersection of every internal bin creates square columns which rise through the full height of the bins.

The arrangement of reinforcing within the walls of rectangular/square bins is entirely different from that found in cylindrical bins. All walls have a double row of reinforcing about 2-1/4" behind the face of each side of the wall. Each row is independent of the other and comprises a system of horizontals tied to verticals.

Within any one wall, both rows have the same components arranged so that the laps between bars are staggered. The verticals of the bins are on 18" centers in the exterior walls and 3'-6" to 5' centers in the interior walls, such that each wall of a square bin has verticals 2' from the corner of the bin, while the long walls of the rectangular bins have four sets of verticals arranged so the spacing increases from 3'-6" towards the corners to 5' at the centers. Where the wall thickens to form pilasters, square section hard grade vertical steel is specified. Similarly, where internal columns are created by the combination of four bin corner fillets, square section hard grade horizontal steel is used. The horizontal steel within the columns and pilasters is graduated; typically, within the pilasters the first 38" above the basement slab is 1-1/4" bar, with the remainder tapering to 1" bar. There are nine or ten such verticals in the pilasters and twenty within the central columning.

In contrast, the horizontal reinforcing system has neither graduation nor variation in the spacing of bars. Throughout the square bin walls, the horizontals are of 1/2" square bar in 12" courses. However, the first 11' of basement walling substitutes 1/2" round rods. An additional system of round horizontals is placed between every course of 1/2" bar, giving a 6" coursing interval to the full height of the rectangular bin walls. The additional reinforcing reflects the greater moments generated within these walls. The horizontal steel extends though pilasters and columns, with corner bars placed across the diagonals of the column fillets. The vertical steel of the columns and pilasters is tied by horizontal hoops of 1/2" or rods at 6" or 12" intervals. The 1" hard steel jacking rods are centrally located within the walls.[47]

THE EVOLUTION OF BIN ARRANGEMENTS

From the earliest years of concrete construction, it was possible to predict the type and intensity of forces within a single bin. However, the forces acting within and between groups of main and secondary bins were less well understood. Substantial moments could be created within the structure, particularly when adjacent bins were storing differing volumes of grain.

The problems of incorrectly engineering interspace bins were revealed by the failure of Haglin's pioneering elevator of 1901. In this incident, a bin wall burst when an interspace bin was full and two of the surrounding main bins were empty. The long contact link walls between bins in Haglin's design were unable to bear the loads placed upon them.

The relative state of loading of adjacent main cylindrical bins creates no bending moments within the bin wall. The main bins are structurally self- contained and all stresses are transferred to the bin slab, or foundation slab, which is constructed to bear the local reversals of loads between adjacent full and empty bins. The creation of an interspace bin between four adjoining main bins can introduce bending moments into the bin walls. As long as the lateral loads bearing on the interspace side of the shared bin wall are equalled or exceeded by those generated from the load in the main bin, there are no bending moments within the wall. If a main bin is unloaded below this point of equilibrium, then the lateral pressure in the bin is reduced and a bending moment is generated in that part of the bin wall shared with the loaded interspace bin. The bending moments are largest when an interspace is full, and all four surrounding main bins are empty. When bending moments are generated, the load is transferred to the outside of the circular arc, and the laws of stresses applicable to circular bins are no longer valid. The bin walls act as an arch and, in order to prevent inward collapse, must be provided with some form of abutment to absorb the thrust of that arch.

Following the failure of Haglin's elevator, designers tended to be conservative and place all bins in tangential contact with a substantially thickened wall occupying the closure between the walls of adjoining bins. Contact anchors of reinforcing bars or rods bridged adjacent bins at the extremities of the tangential wall thickening. The anchors were placed in every course of reinforcing, and were bent about verticals or hooked over horizontals. The potential bending moments in such a configuration were small, and as bin diameter increased, so did the length of thickening about the tangential contact.

The engineering calculations for the Kellogg Elevator (1910) show that the proportioning of the contacts was determined as if they were the abutments of an arch. All early Buffalo elevators featured bins arranged with tangential contacts, an arrangement that was to remain popular throughout the era of elevator construction in Buffalo. Nearly all the bin wall basement elevators--Superior "C" (1925), Marine "A" (1925), Standard Mainhouse (1928) and GLF "A" (1941)--retained this arrangement, as did Buffalo's last elevator, the Connecting Terminal Annex (1954).

Although a convenient solution to the potential problems of interspace bending moments, the tangentially linked bin plan suffered from two disadvantages: the interspace bins tended to be small in relation to the main bins, and the design could not optimize the use of horizontal reinforcing steel. To achieve the greatest economy of steel, the main bins had to be spaced so that the maximum lateral pressure in the interspace bins equalled that in the main bins. The contact between the spread main bins was by link walls, which had to be able to withstand the thrust transmitted from a bin wall no longer in equilibrium.[48]

The first Buffalo elevators that attempted to equate these factors were those designed by H. R. Wait of Monarch Engineering, beginning with Connecting Terminal Mainhouse (1914), Superior "A" (1915), Dellwood "B" (1915), Concrete-Central (1915-17) and Superior (1923); the lineage continued with American Elevator Annex (1931) and H-O Oats Elevator (1931), and culminated in Perot Elevator Annex (1933). Bins were spread both longitudinally and transversely in Wait-designed elevators. The Saskatchewan Elevator (1925-26), designed by C. D. Howe with a Monarch-built mainhouse, is one of only two other Buffalo elevators to show this feature.

The concept of the bin contact acting as the abutment to an arch appears to have been established by 1910, the date the Kellogg Elevator was constructed. A comprehensive set of moment and thrust calculations for the Perot Annex survives, but similar documentation for earlier spread bin elevators does not. Experimental loading tests to determine the moments and thrusts in such structures were not undertaken until late in the second decade of this century.[49]

The Wait designs all featured relatively narrow bins about 20' in diameter, though the Dellwood "B" was an exception with its 25' bins. The link walls were usually straight and linked the closest point of contact between adjoining bins. The Superior "B" Elevator (1923) was unusual in having some curved link walls. In Superior "A" (1915), the link walls are 16" long and 16" thick, and in Concrete-Central (1915-17) they are 2'-8" long and

18" thick. The Dellwood "B" (1916) has link walls measuring 3'-6" with a thickness of 24", while the straight link walls in Superior "B" (1923) are 2'-8" long and 18" thick. The 2'-8" link walls in Saskatchewan are only 8" thick. In the American Annex (1931) the walls are 5'-8", and in the Perot Annex (1933) they measure 5'-4"; both have wall thicknesses of 12".

The Superior "B" Elevator (1923) deploys an inwardly curved link wall between the outer rows of bins. The wall is curved inward and set inside the line of closest contact between bins. These arrangements increase the capacity of the outerspace bins. The Dellwood "C" Elevator (1922) also had bins spread in both directions but employed link walls in a novel fashion, transversely connecting the bins by two link walls, and longitudinally by a single link wall. The link walls were straight and those between any group of four main bins met to form a square bin in the interspace. Between every square bin was an additional interspace bin occupying the area between the two transverse link walls. The outerspace bins extended back to the longitudinal link walls. It is uncertain whether this arrangement was devised for a particular structural reason, though it is known that the elevator was built to serve the New York Barge Canal, and therefore required a greater variety of bin sizes in order to break down shipments.

Whereas there was a general trend towards longer link walls, the changes in link wall thickness are less clear. Until the mid-1920s, walls were thicker than subsequent theory would require, though it was understood that wall thickness should increase with the expansion of bin diameters and height dimensions, as in the Dellwood "B". The relative thinning of link walls in the later elevators represents the application of more precise means of calculating bearing thrusts, the culmination of which is demonstrated by the Perot and American annexes. The relationship between bin diameter and link wall length appears to have been optimized, such that an increase in these dimensions would require thicker bin walls and a rearrangement of the reinforcing steel.

Bending moments and thrusts could be reduced substantially if the bins were spread in only one direction. For a set of 24' bins spread 6' in both directions, maximum moments in the bin wall approached 19,000 ft.lbs. and thrusts absorbed by the link wall 8,000 ft.lbs. In corresponding bins spread in one direction only, the respective figures are 8,500 ft.lbs. and 5,500 ft.lbs.[50]

This arrangement only became popular in later Buffalo elevators, possibly in response to a quantification of the force differences involved. Where the elevator has outerspace bins, the main bins are spread longitudinally, but otherwise all examples in Buffalo are spread transversely. The Lake & Rail Elevator (1927-29) is the only conventional basement elevator in Buffalo to have adopted this bin configuration; it features outerspace bins with longitudinal link walls that are 4'-8" and 8" thick.

The similar position of longitudinal link walls and conveyors within the basement of the "bin wall basement style" elevator resulted in a preference to spread the bins transversely in these structures. Eastern States "A" (1934), GLF "C" (1936), and Eastern States "B" (1946) demonstrate this configuration, having 10" thick 2'- 6" link walls in all cases. The Standard Annex (1941) is the only bin wall basement elevator in Buffalo with longitudinally spread bins. In order to accommodate the basement conveyors, the main link walls were moved towards the center line of the structure, while a supplementary discontinuous link wall (known as a strut wall) was located towards the outside of the structure. Both link and strut walls were 7'-6" and 8" thick.

Although the details of reinforcing within the link walls varied, all contained horizontal link bars or rods coursed at intervals that coincided with those of the main bins. Vertical steel was only used as an independent element of the reinforcing in the earlier elevators, such as Concrete-Central, which had two verticals within the wall. The Wait-designed link walls had two link bars to every course. In the early examples, such as Concrete-Central, these were bent about the single jacking rod at the contacts.

In later examples, two verticals were provided within the bin wall at the intersection of the link wall, and each link bar was bent about an individual vertical. This arrangement was evident in the construction of Superior "B" (1923). As Wait extended the length of the link wall, the arrangement became more complex. The Perot Annex (1933) showed the addition of four contact anchor bars, two at either end of the link wall. The bars were bent about an additional eight verticals, four within the contact wall, and two in each bin wall. The arrangements in Lake & Rail and Standard Annex were simpler; double link bars were hooked over the main horizontal tank bands. In the earlier elevators 1/2" square bars were used for all courses. The Saskatchewan Elevator was the first to use round rod, specifying 1/2" new billet, hard grade steel for all link rods. Subsequently all link rods were of this grade of steel. Perot Annex is the only known example where graduation of the link rods and contact anchor rods takes place.

The overall objective of such complex designs is not only to adjust the capacity of the interspace bin to make optimum use of the reinforcing steel in the main bin wall, but also to balance the thrust taken by the link walls in such a way that the proportioning of the reinforcing in the link and quarter walls, at the coursing interval determined by the design of the main bin, minimizes excess steel.

During the first decade of the century, outerspace bins began to be featured in the design of concrete elevators as a means of optimizing bin capacity. Where bin diameters were small, the outerspaces were also and their outer walls tended to be flat. Volume could be maximized at no additional cost in materials or complication of construction by employing a flat rather than a curved outer wall. Such a form was introduced to Buffalo in the Husted Elevator (1907) which had bin diameters of 19'. The only other example of this style of elevator in Buffalo is the Lake & Rail Elevator Northwest Annex (1930), where the bins were of 15' diameter.

Above a certain main bin diameter, the space saved by straight exterior walls was marginal, and the complications of the unequal stress on a straight wall made it more convenient to construct curved exterior walls of the same radius and thickness as those of the main bins. The Wheeler Elevator (1909), the first in Buffalo to include such bins, was closely followed by the Kellogg Elevator (1910). Both show the characteristic pattern of convex quarter circle outer walls placed between, and virtually indistinguishable from, the main cylindrical bins.

The introduction of spread main bins created larger outerspace bins for a given diameter of main bin. The width of the bin was increased by the length of the link wall and the arc of the outer wall had to be increased correspondingly. To provide a stronger connection to the main wall and deal with thrusts generated by unbalanced loading conditions between outerspace and main bins, the quarter wall broadened to a fillet where it joined the main wall. Superior "A" (1915) was the first elevator known to show this feature. With the exception of the Dellwood "B" Elevator, the line of Wait-designed Buffalo elevators all featured convex-walled, outerspace bins. They usually had quarter circle outer walls; however, where odd diagonal geometries occurred, the outer walls could increase to one-third of a circle.

The bin wall basement elevator did not lend itself to the inclusion of outerspace bins. The difficulties in spreading such bins longitudinally limited the size of the outerspaces, and there were problems providing a convenient means of spouting from the outerspaces to the basement conveyors. The Marine "A" (1925) and Standard Annex (1941) were the only elevators of this type featuring outerspace bins. Marine "A" used an alternative bin arrangement to create large outerspace bins, while Standard Annex incorporated longitudinal link walls in bins laid out in conventional parallel rows. The main bins were placed in three interlocking rows. Interspaces of conventional shape, though with their axis rotated through 45°, occupied the space between four main bins. As the outer main bins had to be spread to accommodate the interlocking inner row of main bins, a larger than usual outerspace bin was formed. The exterior outerspace wall was of conventional convex form.

A section of the inner main bin walling provided the rear wall of the outerspace bins. T. D. Budd, the designer of Marine "A", employed this geometry as a convenient means of installing outerspace bins in a bin wall basement elevator. As the contact walls were set diagonally, they did not coincide with the line of basement conveyors, and the outerspace bins could conveniently be spouted to the conveyor serving the outer row of main bins. The John Metcalf Company specialized in the interlocking bin arrangement; however, its elevators were characterized by concave outerspace walls, as in the Grand Trunk Pacific Elevator, Fort William, Canada. No elevators were built to this style in Buffalo, and the only examples of concave quarter walls occur in the Washburn Crosby complex, where outerspace bins are accommodated within irregular main bin geometries. The H-O Oats Elevator (1931) deployed interlocking bins as a means of creating usefully sized outerspaces where the main bins were particularly narrow (15'). The use of diagonal link walls in this structure further increased the capacity of both inter- and outerspace bins.

Reinforcing in the exterior walls of the outerspace bins followed the pattern established in the main bins. Verticals were placed on centers similar to those in the exterior walls of the main bins and included at least one jacking rod. Horizontals were coursed at the same interval as the main bin. The difference in lateral pressure with height in the outerspace bins was usually small enough for bar/rod size to be standardized. The Kellogg Elevator employed square bars, and the earlier Wait-designed elevators used 1" x 1/4" flats. Both Saskatchewan and Lake & Rail used 1/2" rounds of intermediate grade, new billet steel for all horizontals.

The outerspace rods were only graduated with height in the relatively larger bins of Marine "A", Perot Annex and Standard Annex. Quarter wall horizontals were never lapped as a single rod extended throughout one course. The quarter wall bands were tied to the main bin bands by various means. In the Kellogg Elevator they were bent into short tangs that hooked over the main bin bands. Where flats were used, in the early Wait designs for example, they were bent about the single vertical close to the point of intersection, the direction of the bend alternating with each course. The advent of round rods in elevator work allowed the quarter bands to be hooked over the main bands more easily.

The introduction of the contact anchor as a means of improving the integrity of the joint between the quarter and main walls appears to have coincided with the introduction of round reinforcing rods and was first used in the Saskatchewan Elevator. The quarter wall contact anchors occupied the fillet between main and quarter walls and hooked over the horizontals in both. Subsequently, all quarter bin intersections featured contact anchors. These were bent about verticals in the Perot Annex. The Standard Annex provided no fewer than three at each joint, two tying back into the structure in the conventional fashion and one tying forwards. In the straight-walled Lake & Rail Northwest Annex, the verticals were spaced on 30" centers. The horizontals were arranged in a similar fashion to those in the cylindrical bins. The walls were a constant 6" thickness.

The Electric Annex (1941) represented a radical departure from conventional elevator design, The introduction of front loading plants, assisted by power shovels, made it possible to store and handle bulk grain in large halls. The Electric Annex had six storage halls of about 950,000-bushel capacity each. The elevator retained a central row of conventional cylindrical bins rising from the foundation slab and equipped with a conveyor tunnel below. The central row of conventional bins provided the rear wall to all storage halls, while the remaining bins formed continuous self-buttressing exterior and interior dividing walls. A pitched roof of structural steel clad in corrugated iron spanned the storage halls from buttress walls to the central whole bins. All corner bins were full cylinders, but appear to have been entirely structural and not used for storage. Similarly, where the main walls were stepped inward to accommodate a bend in the river, whole bins provided the end support for the buttress walling.

The tangential contact between the two or three bins of the buttress walling was much more massive than usual. In order to bear the thrust of the grain on the curved walls, the tangential contacts were 17' wide and thickened to 6'. The concrete footings below the contact thickening had a series of keyways into which the subsequently poured contact walls locked. The buttress walling was tied at the bottom and top of the bins by transverse and longitudinal foundation footings and oversize roof members. The 2' x 5' footings, or "basement ties," were reinforced by thirty-six 1-1/4" straight square bars at three levels. The conventional reinforcing within the buttress wall was standardized with that of the entire bin.

The Electric Annex was an example of the giant storage hall elevator. Similar elevators were built in New Orleans and Albany, New York. Storage hall elevators featured whole cylindrical bins to three sides of all storage halls; the height of the remaining exterior buttress wall was much reduced. To accommodate this geometry, the pitched roof of the Electric Annex was abandoned and later replaced by a sweeping concave roof over the storage halls.

THE EVOLUTION OF FOUNDATIONS AND BASEMENTS

The total load on the ground beneath a concrete grain elevator was considerable; two-thirds of the total might be attributable to the live load of the grain, the remaining one-third accounted for by the weight of the structure. The weight of a typical elevator amounted to between 6,000 and 11,000 psf. Few sites in Buffalo could bear such loads without adequate piling or other foundation works. In order to carry the live load of grain most effectively, the elevator designer attempted to reduce or modify the distribution of the load within an elevator.

The earliest concrete elevators were of the tunnel type. The bin walls rose directly from ring footings, where an overall concrete foundation slab bore on piling concentrated in a ring beneath the bin walls.[48] Most of the weight of the structure, together with a large proportion of the live load, was transmitted as compressive force through the bin walls to the ring footings. A hopper bottom formed of slag concrete surfaced with a mortar slab above the foundation slab. The hopper discharged into a tunnel below. The tunnel walls were required to transmit some of the bin wall load, together with some of the weight of the hopper fill and grain in the lower part of the bin. Reinforced as beams, the walls transmitted the bending moments to linear strips of piles. The tunnel floor and slab were reinforced to act as pillars between the beams.

An economical structure to build, the tunnel elevator was relatively lightweight and transmitted much of the structural and live loads directly to the foundation slab at the bin wall ring foundation intersection. However, this elevator was operationally inferior, and the bin walls were prone to horizontal tensile cracking if particular attention was not paid to the structural elements of the tunnel and the bin verticals were not deeply embedded in the ring foundation. Either individual tunnels existed beneath the center line of a row of bins or two parallel rows of bins shared a common central tunnel. In the latter case, the draw-offs occurred at the side of the bin and generated additional bin pressure during unloading.

Buffalo appears to have had only two tunnel type elevators. The Dellwood "B" (1915) was a modified form featuring a central tunnel raised above the foundation but buried within the hopper fill. The bins sat on heavily reinforced ring footings. It is not without irony that the last Buffalo elevator, the Connecting Terminal Annex (1954), is the only true representative of the type in Buffalo, although the central row of whole bins in the Electric Annex (1941) is essentially in the tunnel style.

The full basement elevator was considered to be operationally more convenient. In this style of elevator, the bins were raised and supported on columns or pillars or basement web walling, providing a far roomier basement working area.[49] The total load of the building was increased by the weight of the basement, and the structure became more complex. As conventional fixed form concreting techniques had to be used, the construction process was time consuming and expensive.

Early types of the full basement elevator used pillars to support basement (hopper) beams of reinforced concrete. These deep beams, which carried the entire dead and live load of the bins, were reinforced for both tension and shear, with most bars in the bottom of the beam but with approximately one-third trussed up over the column heads. The beams were usually arranged as octagons in order to support the entire circumference of the bin wall. The American, Perot, and Wheeler elevators employed such an arrangement. At the Wheeler, steel hoppers were supported directly on the beams to the full width of main, interspace and outerspace bins. The Kellogg (1910) used a rectangular network of beams.

As such a geometrical configuration could not directly support the entire circumference of the bin wall, a small area of bin slab and associated hopper slab had to be introduced. The beams also supported flat plate steel hoppers extending across most of the bin bottom. Column loadings were considerable, over 700 tons in the case of the Kellogg Elevator, though rather less with an octagonal arrangement supported by more columns. The distribution of columns beneath an octagonal network of beams was such that an overall basement slab was the most convenient solution to the problem of distributing the load to piling. However, the proximity of rock at both the American and Perot sites permitted the loads to be carried directly via foundation sub-piers. The alignment of the pillars supporting a rectangular network of basement beams was such that more economical footing course foundations could be employed.

The foundations for the Kellogg Elevator were comprised of three lines of piles designed to carry twenty-five tons each.[50] Each line was capped by linear concrete footings, which in turn supported the linearly arranged basement pillars. The footings were reinforced both longitudinally and transversely to distribute the load equally to all piles in the strip. The longitudinal reinforcement was placed in the top on the concrete to counteract upward bending moments between the columns.

The Washburn Crosby complex demonstrates the next phase in the evolution of the foundation and basement arrangements in concrete elevators. While the pillar and beam system enabled the bins to be elevated above the foundation slab, the considerable bending moments that could develop between adjacent full and empty bins were no longer born directly by the slab. The magnitude of this moment could be considerable, and it became common practice to assume that load reversals of 50 percent could occur in those parts of the structure that supported the bins.

Washburn Crosby "B" and "C1" elevators (1909) were the first in Buffalo to adopt a full structural bin slab. The bin wall and bin bottom loads were no longer carried directly by basement hopper beams, but supported by an overall 16" thick bin slab.[51] Designed to carry the full vertical live and structural load, the slab supported a hopper fill of slag concrete surfaced by a mortar hopper slab, which directed grain to small steel hoppers countersunk into the bin slab.

The slab was carried by beams framed into a system of basement cross walling. The cross walls were placed to support the greatest possible length of bin wall without disrupting the basement conveying systems. Diverse arrangements of cross walls supported the bins directly by at least four segments of basement walling, and minimized bending moments in the bin slab without disturbing basement conveying systems. In the "B" Elevator walling was comprised of units of elongated octagons, each with four transverse walls supporting two bins. The "C1" Elevator employed a similar arrangement, though the elongated walls of the octagon were truncated, the transverse walls reduced in number and longitudinal walls introduced. These changes in geometry provided direct support below every bin contact.

The configuration of walling in the "C2" Elevator (1913) was an even more complex grid of discontinuous transverse and longitudinal walls which formed squares that provided support between the bin contacts. The basement cross walling was supported by an overall basement slab; however, the piling only needed to be concentrated in the vicinity of the walling. In the Washburn Crosby "C1" Elevator such a piling pattern loaded no pile to more than twenty tons.

Although a structurally elegant solution to the problems of supporting concrete bins, piling added significantly to the weight of the structure, and the complex and extensive network of basement walling hindered internal operations. In the Washburn Crosby "C1" Elevator, for example, less than 50 percent of the total weight of the structure from the top of the bins to the top of basement slab was accounted for by the bins, the balance being due to the bin slab, hopper slab and fill, and basement walling.[52]

The solution to the problem of providing a basement uncluttered by web walling required the installation of a bin slab better able to deal with the moments induced when adjacent bins contained differing volumes of grain. A slab designed to withstand cantilever action, both within individual and between bins, could be adequately supported by basement columns or pillars. The series of elevators designed by H. R. Wait, beginning with Connecting Terminal in 1914 and ending with the Perot Annex of 1933, used a 14" thick bin slab supported by basement columns on 12' centers. The hopper arrangements were analogous to those in the basement wall designs.

Concrete-Central and Superior "A" and "B" elevators have bin slabs reinforced by groups of five bars running transversely, longitudinally and diagonally over the column heads. Two bars in every group are trussed over the column, and all bars are square lugged. In the Howe-designed Saskatchewan Elevator, the bin slab reinforcement consists of ten rods running longitudinally and transversely between each column head. The system provides five straight lower rods between each column, with the remaining rods trussed over the column heads. The rod sizes increase from the outer aisles to the inner aisles.

In the early elevators, the bin slab was supported on 42" square pillars with a 72" pyramid head, and the pillars in the outer row were rectangular, 24" x 60", with bracketed heads. The columns were arranged in equidistantly spaced rows so that four pillars lay below every main bin. The rectangular outer pillars were placed below the intersection of the main and quarter bin walls. Designed to carry 399 tons each, these pillars were reinforced with twelve 1" verticals and horizontal hoops at 12" intervals. The Concrete-Central "C," "D" and "E" (1917) elevators were the last in Buffalo built to this pattern.

Although generally maintaining the same geometry, mushroom-headed columns were substituted for square pillars in subsequent elevators, such as Superior "B", the first Buffalo elevator to use them. The mushroom-headed columns of the Saskatchewan Elevator were designed to carry 440 tons. In later elevators, the general configuration was maintained in the inner rows of columns, but changes were made in the arrangement of outer wall pillars. The outer pillars in the American Annex were no longer placed below the intersection of the main and quarter walls, but below the middle of those walls. In the Perot Annex (1933), the rectangular pillars were replaced by mushroom-headed columns occupying the conventional location below the main and quarter wall intersection. The H-O Oats Elevator (1931) shows another variation with the columns placed below every link wall. While the configuration of small interlocking bins explains the column arrangements in the H-O Elevator, an explanation of the changes in the Perot and American annexes is more difficult. The elimination of the wall pillars in the former may have been stylistic rather that structural. No longer interrupted by pillars, the basement walling could be embellished with continuous elongated windows.

The Lake & Rail Elevator (1927-29) represents a transition between the basement wall and the basement column types. The 12" thick bin slab is reinforced by a regular grid of straight rods on 12" centers; however, the slab is supported on massive transverse basement beams that vary in depth from 2'-6" in the middle aisles to 3'-6" in the outer aisles. These beams are reinforced with trussed 1-1/4" and 1-1/2" rods and supported on bracketed rectangular pillars. The pillars are arranged in rows so that four pillars and two transverse beams lie below every main bin. Unlike the arrangements in the other bin slab elevators, pillar dimensions progressively increase toward the outside of any transverse row as the separation between pillars increases. The overall result is a widening of longitudinal aisles toward the outside of the structure.

With the exception of the Lake & Rail, American Annex and Perot Annex elevators, where each pillar or column is carried by a foundation sub-pier founded on rock at a relatively shallow depth, all elevators of this style were supported on piles. The column loads were carried to a substantial foundation slab. Originally the columns landed directly on the foundation slab but stepped landings were provided with the introduction of the mushroom-headed column in Superior "B".

The density of columns required piles to be placed at regular intervals beneath most of the foundation slab, though some grouping was possible beneath the column footings. The piles were tied by a widely spaced diagonal network of 1-1/4" bars. As little bending moment was transmitted to the slab, the area below each column landing was reinforced by a discrete grid of 1-1/4" and 1-1/2" rods doubled or quadrupled to reflect the load of the column. A thin, lightly reinforced floor slab was installed on gravel infill above the foundation slab. The Saskatchewan Elevator was exceptional in having a heavily reinforced floor slab, a foundation slab reinforced with a lower continuous grid tying every pile and an upper system of trussed longitudinal and transverse rods on 4" centers. The reason for this departure from accepted practice is unknown.

For a given basement height, the basement column style of construction resulted in significant savings of material. The weight of material in the bin slab, hopper fill and slab, and the columns and footings, represented 30 to 35 percent of the total weight imposed upon the foundation slab from the bin tops downward. The comparable figure for the basement wall type of elevator was 50 percent. However, most of the other difficulties remained, such as the weight of a basement structure that could not be slip formed. The fixed form work necessary to produce the numerous mushroom-headed columns was considerably more complex than that required for a basement wall.

The most radical change in the basement arrangements of concrete elevators came about through the work of T. D. Budd, whose design was patented in March of 1921. By combining elements of previous designs, Budd produced an elevator that was simple to construct and inexpensive to build. Budd's design not only used less material, but also provided 5 percent more storage for a given bin dimension, distributed its load more evenly upon the foundations and contained a spacious basement conveying area. The behavior of grain when stored in a deep bin made the new design possible. Budd recognized that the bin walls transferred most of the weight of the stored grain to the base of the bin. The only significant loading on the bin bottom was produced by the grain within the cone of hoppering and the grain above the hopper to a height equivalent to the diameter of the bin.[53]

Realizing that it was possible to gain the economy of the tunnel type elevator, Budd used ring footing foundations and slip forming from the foundation slab without sacrificing basement space. As little weight was carried on the hoppering at the base of a bin, Budd discovered that a full-width steel conical hopper bottom could be raised on pilasters of moderate proportions to a height within the bin sufficient to provide an adequate basement. The principle of the design is illustrated by the 21" diameter, 84" deep bins of GLF "C" (1936). Although the bin has a capacity of 1-3/4 million lbs. of grain, only 0.35 million lbs. bear directly on the bottom of the bin. The weight of this grain was transferred to the foundation slab by six 1'-2" x 1' columns, each carrying sixteen tons. The weight of the remainder of the grain was transferred to the foundation slab via the bin walls. Only 20 percent of the weight of the structure from the bin top to the foundation slab was not used to contain grain. The design was adopted widely; with the exception of Buffalo's last conventional basement elevator, the Perot Annex, completed in

1933, the experimental Electric Annex and the retrograde Connecting Terminal Annex, derivatives of Budd's design excluded all others.

The Marine "A" Elevator (1925) represents Budd's design in its purest form. The conical steel bin bottom is elevated 14' on eight 9" deep pilasters inside the bin wall. The pilasters support a U-channel annular steel ring attached to the hopper by brackets. The interspace and outerspace bins are provided with flat plate steel hoppers supported on I-beams. Bin walls rise from foundation beams reinforced with straight rods. Concrete caissons provide the foundation to rock, which is relatively close to the surface at this site.

All other examples of this type display modifications to the original design. The bin wall pilasters and annular steel ring have been replaced by radially arranged basement pillars. These pillars support the concrete ring girder in which the hopper bottom rests. The ring girder abuts the bin wall, but is not structurally keyed to it. The Superior "C" Elevator (1925), also designed by Budd, was the first Buffalo elevator to deploy these modifications. Its ring girder was 5' deep and 6' wide and supported by eight 10' high pillars measuring 3'-9" x 1'. Bin walls and pillars stood on a concrete foundation slab supported by a ring of piles. Piling was absent below the center of the bin, the point at which the slab begins to thin.

The work of Buffalo-based elevator designer A. E. Baxter became synonymous with this style of construction. The Standard Elevator Mainhouse (1928), the first of a series of Baxter designs, was followed by Eastern States "A" (1934), GLF "C" (1936), GLF "A" (1941) and Eastern States "B" (1946). In Baxter designs, the ring girder is modified so that its inner face is twelve-sided, the curved outer face abutting the bin wall as in Budd designs. The girder carries a standard conical steel hopper. Every other face is supported at its center by a radially arranged pillar. The six pillars required to support the ring girder are freestanding in all Baxter elevators, with the exception of the Standard Elevator, where they abut the bin wall in order to be completely supported at their base by the foundation beams.

In all Baxter elevators the pillars are substantially smaller than those of Superior "C", ranging from 2' x 1'-4" in Standard to 1'-2" x 1' in GLF "C". The twelve-faced ring girder simplifies reinforcing; rather than having to form bars to the radius of the ring, twelve sets of straight bars may be used. This reinforcing pattern is typified by that in GLF "C" with its horizontal reinforcing of seven straight rods, two on the top and one on either side at 2-1/2", and three on the bottom hooped at

16" centers with 1/2" rods. In no case was the reinforcing tied to the bin.

The hoppering was 45° in the GLF "C" and Eastern States "A" elevators and 55° in the Eastern States "B" (1946) and GLF "A" (194). All these elevators were constructed to supply feed mills, and the steep hoppering was required to deal with some of the materials handled, particularly brans. Unusually tall radial pillars were required to achieve steep hopper angles, such as those in Eastern States "B" at 14'-8" high. The bin bottoms and radial pillars of Standard and GLF "A" rest on basement beams in an arrangement similar to that at Marine "A". The beams are carried by concrete caissons and spanned by a light floor slab. GLF "C" and Superior "C" have similar foundation slab and ring piling arrangements. The interspace hopper bottoms are of slab concrete carried by concrete girders spanning the main bin walls. In Eastern States "B" the support of the girders is aided by pilasters added to the main bin wall.

The Standard Annex (1941), with its fully circular ring girder supported on eight radial pillars, features Buffalo's only conical hopper bottoms of reinforced concrete. The unusual foundation arrangements consist of rectangular sub-piers erected on rock. These piers are centered below the bin contacts, link walls, strut walls, and the intersection of main and quarter walls, but broaden at the head in order to support the radial basement columns. Interspaces have concrete slab hoppers supported on a central longitudinal beam. The outerspace slab hopper is supported by the strut wall.

THE EVOLUTION OF HEADHOUSES, WORKHOUSES AND GALLERIES

Although the change to concrete storage bins on concrete foundations took place rapidly during the first decade of the century, the structures above and beside the bins were in transition far longer and retained vestiges of both steel and tile construction. Concrete bin floors had been used both in wooden elevators like the Husted (1899) and iron elevators like the Iron (1901). However, to simplify the completion of the slip forming process, most early concrete elevators had bin floors of book tile skimmed with mortar. This floor covering allowed the retention of forms without the removal of jacks and yokes. The book tile was applied to the I-beams that had been used to support the working floor during construction.

All the early Wait-designed elevators employed this method of construction. The Kellogg Elevator (1910) and the Washburn Crosby elevators (1909 and 1913) had concrete bin floors, but it was not until the 1920s that such monolithic concrete bin floors became universal. The concrete was placed on the working platform and supported by the I-beams that were raised with the forms during construction. Reinforcing patterns varied but all incorporated diagonal or longitudinal grids. Exceptions to the general trend included open-topped bins, a feature the Wheeler Elevator shared with the crib bins of wooden elevators. The Chicago and Southwestern Elevator at Chicago, also with open-topped concrete bins, suffered a massive collapse after a grain dust explosion in 1913. Following the destructive grain dust explosion at Eastern States "A" in 1937, all subsequent Baxter-designed elevators featured individual concrete bin caps. It was hoped that the caps would confine explosion damage by blowing off and relieving pressure on the bin wall.

The timetable for the construction of an elevator was usually extremely tight. Slip forming began only when spring was far enough advanced, yet the promoters expected the building to be operational by autumn to receive the first of that year's crop and ensure that storage was full at the close of the navigation season in mid-December.[54] An elevator was unable to receive grain without headhouse, workhouse and gallery. Therefore, it was imperative that these structures were completed as soon after the storage bins as possible. Concrete headhouses, workhouses and galleries only became widespread as improved cements and the application of complex slip forming techniques ensured rapid completion of these structures. Before such innovations were introduced, concrete construction above the bin floor could not commence until the concrete below had set sufficiently to bear the weight of the new structure. However, when concrete was used, the complexity of construction required the use of slow and expensive fixed form techniques.[55]

The galleries, headhouses and workhouses of early elevators tended to be built of quickly erected and relatively light structural steel. Corrugated iron was the most typical cladding material, although plaster on a ferro-enclave mesh was also used, as in the Washburn Crosby "C1" and the Connecting Terminal; floors and roof were usually of concrete. The workhouse bins and garners and the headhouse garners were of steel plate. Concrete construction was first applied to the workhouse as it could be raised by slip forms directly from the foundation or bin slab. The small workhouse of the Husted Elevator provided an early example of this transition. That part of the workhouse below the bin floor was raised with the bin forms, while the upper section used conventional structural steel techniques. The drier garner bin in the lower part of the structure was of concrete but the scale garners in the upper part of the structure were of conventional steel construction.[56]

Although the Washburn Crosby "C2" Elevator (1913) was the first in Buffalo to use concrete in gallery construction, fixed forms were used. By the second decade of the century, concrete was widely employed in above bin structures elsewhere in America, but Buffalo did not adopt this form until the 1920s. Its use in Buffalo had to await the application of slip forming to this aspect of elevator construction.

The Ralston Purina Workhouse (1917), designed by A. E. Baxter, established the practice of monolithic construction of workhouses and headhouses by slip forming in Buffalo. Complex slip forming techniques permitted the continuous pouring of the workhouse upward through the basement, square workhouse bins, distribution floor, scale floor, concrete scale garners, and machinery floor. Similar workhouses were to follow at Marine "A" (1925), Lake & Rail (1927), Standard (1928), Eastern States (1934 and 1946), and GLF "A" (1941). Slip formed headhouses containing distribution floors, scale floors, concrete scale garners and machinery floors were built at the Saskatchewan (1925) and Superior "C" (1925) elevators.

The complex structural arrangements at Standard Mainhouse (1928) are typical, though subdivided cylindrical main bins take the place of rectangular lower workhouse bins. Pier and panel construction is used with the respective wall thicknesses of 12" and 8". The piers coincide with division of the rectangular scale garner bins and serve to strengthen the fillet at the intersection of bin walls. Transverse beams support the distribution floor, scale floor and hoppers, the garner bin bottoms, and the machinery floor in ascending order. The spacing and dimensioning of the beams vary, but the largest are those required to support the garner bottoms and the elevating machinery.

Jacking rods are located centrally within the wall on 5'-9" centers independent of the main reinforcing. The main reinforcing within any wall is made up of inner and outer verticals and 1/2" horizontals. The inner and outer verticals are offset and vary in number, the most frequent occurring every 15" in the scale garner bin. The horizontal rods are graduated and coursed at varying intervals. The dimensions and coursing of inner and outer rods vary independently. The horizontal coursing, at its most dense every 3" along the base of the scale garner bin, graduates upwards to resume the average 12" coursing towards the top of the bin. The graduation of verticals in the workhouse garner bins contrasts with the simpler non-graduated arrangement in the typical non-cylindrical workhouse's storage bins, as in GLF "A." Whereas the storage bins are of relatively small cross-sectional area and have a single central draw-off spout, the shallower garner bins have a larger cross-sectional area.

Draw-off takes place through nine spouts in the examples at Standard Mainhouse. The frequent and rapid draw-off of grain through multiple spouts during weighing operations can produce surge pressures which are transmitted to the garner bin walls. Additional steel is required to allow for this condition. In an attempt to reduce explosion damage by checking the spread of explosions to other parts of the building, lighter gallery and head and workhouse curtain walling was introduced during the 1930s.[57] It is unclear whether this precautionary measure was adopted in Buffalo.

THE EVOLUTION OF SLIP FORMING

From the outset, American grain storage bin construction techniques departed radically from European practice. Within less than a decade, all major elevator builders employed slip forming during construction of the grain bins. Although Europeans had pioneered concrete grain storage, the greater efficiency of American methods might be judged by comparative construction rates. In 1912, when the Manchester Docks No. 2 Elevator was raised at the rate of 18" per week, comparable storage units in America were rising at 4 to 5' per day.[58]

Slip forming involved the continuous raising of a single set of forms to which concrete was added for twenty-four hours a day. The slip form method saved labor and material costs, speeded construction and produced superior structures. When fully developed, the technique produced a monolithic, finely finished bin wall devoid of lift breaks where moisture penetration might occur. The structure was produced rapidly and economically. The large amount of timber, labor and time required to erect fixed forms from scaffolding was eliminated. Scaffolding was dispensed with altogether, and the concrete finishers only required the suspension of a working platform below the forms. The use of cranes was minimized, as all bars were loaded onto the working platform before jacking commenced. Both concrete and reinforcing could be placed more easily in the shallow slip forms, than in the deeper fixed form work.[59]

Haglin dispensed with fixed form work and devised a system of forms moved by jacks. The patented system was employed during the construction of the 1899 experimental bin.[60] Haglin's design established the basic concept and components that were later to develop into the full slip form. It consisted of two steel angle frames to which were attached vertical timbers forming two concentric forms. The forms, held in place by steel yokes, were separated by a distance equal to the required wall thickness.

After the concrete was poured between the molds and sufficiently set, jacks were placed on top of the hardened concrete, engaged in hooks on the framework, and used to lift the molds into position for the next pour. The work progressed at the rate of one lift of the forms per day.

In 1900 the John Metcalf Company built four circular concrete bins for George T. Evans at Indianapolis. These were raised by forms that were jacked from the surface of the newly set concrete; however, as yokes were absent, the forms were separated by bolts. In 1901 E. L. Heindenrich, a notable pioneer in concrete elevator construction, devised the system of forms providing the basis for subsequent "shifting panel" construction techniques. That year Heindenrich built a cement storage elevator with four circular bins. The forms were of steel and consisted of eight interior and eight exterior curved plates connected by iron yokes. The plates were arranged so that the lower part of the inner and outer plates could be clamped together in sections and supported by friction against the bin wall, while the concrete was placed in the upper part of the form. Once the concrete was sufficiently set, the form work was lifted in individual units by block and tackle on gin poles to be reset for the next filling of concrete.

Shifting panel construction did not involve the continuous pouring of concrete; rather, concrete was placed in discrete lifts and, once sufficiently set, the form work was moved upwards to receive the next lift of concrete. To speed operations, double or triple sets of panels were shifted over each other in turn. When concrete had been placed in the uppermost group of panels, the lowest group, now containing set concrete, was lifted above all other panels in preparation for the next lift.

By the second decade of the century, a number of engineering companies were marketing patented forms for the construction of circular storage bins. Such methods appear to have achieved some popularity in the construction of small "country" elevators where slip forming methods found less favor due to the complicated logistics of continuous pouring. Most systems featured steel form work that permitted "a great deal of time to be saved in the raising and placing," and produced forms "true to size and perpendicular." The various systems sought to eliminate the need to carry scaffolding to the full height of the structure and featured means by which the panels could be manipulated with ease by a minimal labor force.

The steel forms supplied by the McCoy Company were in upper and lower sets supported by staging within the bin walls. More innovative designs used similar sets of forms but employed a steel mast that was placed centrally within each bin. The mast supported a derrick by which the forms could be lifted and the working platform from which the forms were manipulated and the concrete was poured. This system eliminated the need for conventional staging. The basic design was developed into a movable form in which a single form set, together with the working platform and all equipment, was supported from the central mast. The entire structure was lifted by a lever jack that bore on a casting pinned to the mast. It does not appear that slip forming was carried out using these forms. Rather, concrete was poured in discrete lifts and left to set before the forms were moved.

Most forms were built to erect bins of a single diameter. However, the Blaw Steel Sectional Form appears to have been particularly popular, as it could be readily adjusted for various bin diameters. The system was composed of a double set of forms each about 2' deep. The forms were made up of individual 18" long panels of sheet steel. The panels slotted and locked into a system of 6' long upright channel bars arranged on 18" centers about the circumference of the bin. By adding or subtracting these panels, the diameter could be altered. At any one time, the channel bars contained both upper and lower panels and had sufficient length remaining to accommodate the next shift of panels.

As building work progressed, the channel bars were raised in 2' increments so that they might accommodate the next shift of panels. No scaffolding was required in this form of construction because work was carried out from temporary staging placed across the bins. The panels were light enough to manipulate by hand.[61] The 160' tall Kellogg Loading Bin of 1911, apparently the only example of its type in Buffalo, shows the prominent lift breaks characteristic of shifting panel construction. It is not known which form system was used.

The King Elevator at Port Arthur was the first structure to use movable forms that were slipped while the concrete was still wet. This elevator was built by the Barnett Record Company in 1904 to the design of R. H. Folwell. Folwell devised a prototype system of moving forms that was to incorporate all the common elements of later derivatives. He envisaged lifting the concentric inner and outer timber forms by means of a specially designed hollow screw jack attached to the yokes. The jacks reacted upon 1-1/4" jacking rods set in the bin wall and were retained within it as an integral part of the vertical reinforcing system. The original plans were abandoned due to the cost of the jacks, fifty-six of which were required to raise the nine bins.

In spite of this, the forms were raised by simple jacks bearing upon timber posts erected within the bin wall. The eight posts required per bin were braced by scaffolding. The forms were raised so jacks would reach the limit of their travel, and, once reset, another section of post was added below each jack. Although it was intended to pour distinct 12" lifts of concrete, and only raise the forms when these were set, experiments were conducted in raising the forms continuously. Construction was expedited by continuous lifting of the forms at a steady rate while the concrete in the upper part of the forms was still plastic. However, as concrete was not poured twenty-four hours a day, the movable slip forms did not produce a truly monolithic structure devoid of lift breaks. The same year the Missouri Pacific Elevator at Kansas City was built by the John S. Metcalf Company using similar methods, but with the jacks placed at the bottom of the bin instead of at the top adjacent to the form. Metcalf patented this system in August of 1904.

The MacDonald Engineering Company was the first both to attach the jacks to the form yokes and to raise the forms on vertical rods (actually tubes) which remained embedded in the wall after construction. The externally threaded jacks reacted upon short lengths of hollow jacking tube. At the end of travel, the jack was reset and a new length of jacking tube inserted. The bins constructed at Jefferson Junction in 1904 were raised by this method; however, the concrete was poured in discrete lifts, rather than slip formed and the forms raised once a day.

The American Elevator (1906) is thought to have been the first elevator raised by slip forming operations that were carried out night and day to produce truly monolithic bin walls. Designed by R. H. Folwell, now of the James Stewart Company, the forms were raised by a method similar to the Metcalf system in which jacks located on the basement floor acted on posts connected to the form yokes. The posts were positioned within the bins and braced radially to the bin walls. The arrangement differed in that a timber jacking cage was placed between the posts and the jack. When the jacks had reached their full 12" of travel, they were reset, the cage was lowered, and additional post timber added above the cage. This jacking system was cumbersome, slow, and costly in both timber and labor.

By 1906 the MacDonald system had evolved into a form which was to require little modification over the ensuing years. A hydraulic, lever-operated pump jack was substituted for the screw jack. The system continued to operate by the jack pushing directly on short lengths of tube or rod. First used on the Santa Fe Elevator in Chicago in 1907, the system may have been employed in Buffalo as early as 1908 during the construction of the Husted Elevator. The Eastern States Elevator of 1934 was constructed using the MacDonald system.

The Folwell-Sinks jack, patented on April 6, 1907, represented the final realization of Folwell's concept of 1904. A screw jack with an externally threaded hollow screw, a clutch and a jaw mechanism was mounted on the form yokes. The solid jacking rod passed through the hollow jacking screw and was gripped by the jaw mechanism. At the limit of jack travel, the jaw was released via the clutch, the jack reset, and the jaws re-engaged on the jacking rod. When necessary, a new section of jacking rod could be fed through the hollow jack screw and spliced to the old rod. The great advantage of this mechanism was the length of unspliced jacking rod permitted. Although time was saved in the assembly of the rods, the long lengths of rod above the jacks hindered the placing of the horizontal tank bands.

The Folwell-Sinks system was employed in all post 1907 James Stewart elevators built in Buffalo including the Washburn Crosby complex (1909, 1913 and 1926), Standard Mainhouse (1928), GLF "A" (1941), Superior "C" (1925), Marine "A" (1925), and Eastern States "B" (1946). The Metcalf Company[62] and the Monarch Company[63] used another form of jacking device. In this system the jacking rod was threaded and passed through a nut which was attached to the form yoke. The nut was turned to raise the forms on the threaded jacking rods. To minimize binding of the threads, the rod and nut had to be held in alignment. That part of the jacking rod above the yoke was supported by an upward extension of the form framework, while below it was guided by a sleeve centered in the yolk framework.

The system provided a positive drive, capable of exerting considerable power should the forms stick. Long lengths of jacking rod could be accommodated, and the forms could be raised more efficiently as the system only had to be reset at the end of the jacking rod, rather than at the limit of jack travel. However, such advantages were obtained at the expense of threading the rods. In Buffalo, Connecting Terminal (1914), Concrete-Central (1915-17), Superior "A" & "B" (1915 and 1923), and possibly Saskatchewan Elevator (1925-26) were built using this system.

Manual labor was used almost exclusively to raise the forms; however, in 1918 the Barnett Record Company introduced a mechanized system in which hollow screw jacks were driven by worm gears via chain and line shafting from electric motors. The Fegles Company operated a compressed air system that supplied individual air jacks with air from a centralized compressor. It is possible that the Dellwood "C" Elevator (1922) in Buffalo was constructed by this system.

The depth of the forms varied from 3-5' to 4'-6" deep and was broadly related to the setting time of the concrete. The concrete had to be contained within the forms until it set sufficiently to bear the unsupported weight of the concrete above and to allow the jacking rods to support the weight of the forms and deck and withstand the push of the jacks. If the forms were too shallow, or raised too quickly, break-outs would occur immediately below the forms. The deeper the forms, the greater the drag between wall and form, and the greater the number of jacks and jacking rods required to lift any one bin.

The development of slip forming was dependent on the availability of comparatively fast setting cements in America.[64] During the early years of slip forming, the rate of construction was limited to about 5' per day.[65] Wheeler was raised 4' per day in 1909.[66] During the second decade of the century, high early-strength cements and improved mixing and delivery techniques had increased that rate to 8' per day. With the cements now available, it was necessary to retain the concrete within the forms for twelve hours so that break-outs might be avoided. As a result, the 4' form became an industry-wide standard, allowing the wall to rise to twice the form depth in twenty-four hours. Experience had shown it advisable to pull between 60 and 70 square feet of form per jack. Accordingly, the standard 4' form was pulled on jacking rods placed at 8' intervals around the circumference of the wall. At this spacing, each jack pulled 64 square feet of form.[67] By the late 1920s, improved cement technology permitted building rates of 12' per day using the standard 4' forms.[68] Twenty years later, rates approaching 20' per day were attained with air-entrained concrete poured into 4' forms.[69]

Early forms were too heavy and rigid, and changes in the components and the choice of material were directed toward lightness and flexibility of the forms.[70] Heavy forms required a greater depth of supported concrete, and rigidity was likely to cause lifting in the structure should the forms lose their level.

The basic principles of form construction were established with the building of the King Elevator in 1904. Vertical timber staves with chamfered edges were held near the top and bottom by a timber ring composed of laminated segments. Inner and outer rings supported their respective forms. The inner and outer segmental rings were linked by a yoke, which consisted of an inner and outer upright linked above the form by a horizontal carrying the jack. The application of steel to both the form and its framing proved to be unsuccessful due to its weight and rigidity. The early steel-framed yokes tended to be abandoned in favor of those made of timber. Once the superiority of timber had been established, modifications tended to be subtle; flexible joints were introduced between the forms of adjacent bins, and the outward staves tapered to reduce sticking of the forms.[71] The flexibility of a timber system was confirmed when slip forming was applied to more complex structures, requiring form components that might be added or removed with ease.

Although initially applied to the cylindrical bins, slip formed rectangular bins soon developed, the MacDonald Company building the first examples at Evansville in 1906. The concept of slip forming was thought to be only applicable to simple uniform structures with thick walls rising over 20'. However, by the early 1920s, the complexities of headhouse and workhouse construction were being tackled by slip form processes. This work involved the slip forming of pillars, curtain walling, beams, and in some cases, floors. The basic principles and plant remained the same, but more complex processes of blocking, filling, choking and casting off of forms were also carried out.

European construction methods remained highly conservative for the first quarter of the twentieth century. It was not until the 1930s that American "sliding panel" (slip forming) techniques were widely applied to the construction of grain storage units in Europe. The slow uptake of this technology is attributable to a number of factors: the relatively inexpensive and abundant labor available provided little incentive for the application of labor-saving methods; European cement technology lagged behind that of America for the first two decades of the century, and while the industry had little demand for high-strength cements it was unlikely to develop products suitable for slip forming; the logistics of construction for a non-slip formed structure were simpler and the reliability of mixing plant less critical; with day shift labor sufficient for most operations, smaller units of storage for the reception of grain were more convenient than was the case in America. Relatively shallow 75'-80' square/rectangular bins were most applicable.

Bulk handling methods did not develop to the same degree as in America. The dispatch of grain by labor-intensive sacking operations also favored the smaller unit of storage. Materials for shipment were drawn from storage and sacked up for transfer to rail or road. Sacking up took place beneath the bins, and it follows that the greater the number of bins, the larger the number of simultaneous sacking operations. The method of dispatch required a high two-story basement. The construction of such high basements necessitated relatively high scaffolding before bin construction could begin, and it was probably considered little more trouble to carry it to the full bin height. Although the rectangular/square bin could be slip formed, the technique did not lend itself to the optimum use of materials, it being difficult to achieve economies of material by the variation of bin thickness with height and the installation of trussed horizontals.[72]

It would appear that the European engineer was prepared to sacrifice speed of construction for an optimally engineered bin that satisfied the operational needs of the grain trade. Conventional form work seems to have been used almost exclusively for the first two decades of the century. Slip form work was only introduced on a relatively small scale after World War I.[73]

Shifting panel techniques became preeminent during the 1920s. The forms were divided into relatively small unitized sections that could be moved either by a crane placed on top of each bin or manually from scaffolding. For cylindrical bins each panel was about 8' long, while in rectangular tanks, the panels usually corresponded to the length of each wall. Lifts of concrete measured the depth of the panels, usually 2' to 2'-6". The vertical arrangements varied as single, double or triple sets of panels were used. Concrete was allowed to harden in one or more lifts while the panels from preceding lifts were dismantled and re-erected for the next lift. The steelwork was put in place before the panels were re-erected.

Although structures originally required full scaffolding, special systems were developed to minimize these requirements. With multiple form sets, slots were incorporated into the bin corners from which temporary scaffolding could be erected to effect the next shift of panels. Where single panel sets were used, inner and outer panels were held together by bolts. At the base, they passed through the concrete, while at the top they formed a semicircular groove across the top of the concrete. When the panels were lifted, lower bolts placed in these grooves fixed the panels in position. Thus a series of bolt holes was formed in the wall, providing a means of attaching the temporary working platform from which the panels could be manipulated. By the late 1920s, structures could rise at 1' per day using such single shifting panels and high-strength cement.[74] During the 1920s all three methods appear to have coexisted. However, by the 1930s, slip forming had proven the most efficient technique. A "world record" was established in 1933 during the construction of the Royal Victoria Silos, London, where 88' of bin wall was raised in seven days.[75]

BUILDING AN ELEVATOR

Elevator construction was undertaken by the relatively few companies who specialized in this field or who combined elevator and mill construction. Design was either by company engineers or by specialist designers contracted directly by elevator promoters. The Monarch Engineering Company, with C. D. Wait as design engineer, was a notable local example of the former. This company not only built to Wait's designs, but also contracted to build to the plans of specialist designers, as in the Saskatchewan "A" designed by C. D. Howe. The A. E. Baxter Engineering Company, a prominent local example of the latter, would undertake to design an elevator or mill, and the promoters would seek tenders based upon this design from an elevator builder.

The design company was often the supervising engineer to the promoters during construction. The construction company usually had a strong design team of its own. The Standard Elevator (1928) was designed by A. E. Baxter and constructed by James Stewart and Company. Yet three years earlier, that company had built the Marine "A" and Superior "C" elevators to the in-house design of T. D. Budd. However, the promoters of both of these elevators appointed A. E. Baxter as resident engineer. Although the builder usually undertook to both construct and equip the elevator, contracts could be split. In the case of the Lake & Rail Elevator, the structure was built by Jones Hettelsetter and Company, the marine towers designed and built by the Monarch Company and the elevator equipped by an unknown third company. At Saskatchewan, the foundation works were carried out by the Barnett Record Company, while the first phase of elevator construction was let to Monarch Engineering.

The process of building an elevator followed a well-established seasonal pattern. Plans detailing every element of construction and equipment would usually be worked up in the autumn to be ready for the following year's building season. A "bill of bars" was drawn itemizing all reinforcing bars, indexing their precise position in the structure, and specifying their dimension, shape and steel specification. A "schedule of courses" was produced to indicate the location and size of the tank bands and the position of verticals and jacking rods. Detailed plans of the wooden forms were produced for the on-site carpenters. The position of all machinery had to be predetermined with accuracy so that mounting bolts, plinths, etc. could be incorporated as the concrete was poured.

Work generally began in the winter on the foundations and involved excavation and pile driving. Where concrete caissons were to be cast, a steel shell had to be sunk into the rock. As it was driven, material was removed by a special pump. The concrete was poured in a number of lifts, the steel shell being pulled to the top of each lift following pouring.[76]

As piling proceeded, a concreting plant was established for material storage, mixing and conveying equipment, elevating tower and carpentry and bar bending shops. The efficient progress of the movable forms required a mixing and delivery system capable of supplying concrete at the volume determined by the rate of lift and area of the forms. For large jobs it was more efficient to raise the elevator in several lifts; the 1917 extension to Concrete-Central was raised in three, and the Standard (1928) in two discrete sections.

Aggregate for Buffalo elevators was generally supplied directly from the Seneca Shoals of Lake Erie. The specification of the dredged material was closely controlled. The gravel was to be clean and composed of round stones between 1/4" and 1-1/4" in diameter. The sand needed to be well-graded, from fine to course, but with the latter predominating. As the shipments arrived at the dock sieve, analyses were made, and, if necessary, screened sands and gravels from other sources were added to achieve the desired proportioning.[77] The sand and gravel were then stockpiled to be conveyed to the mixing bunkers as required. Bagged cement was stored in a dry on-site storage house. It was to be first-class Portland cement, free from lumps, and well-seasoned.[78] Either a complete laboratory report was required on all shipments or on-site tests were made to determine the strength of the cement.

From the earliest years, concrete for elevators was mixed by machine.[79] To ensure accurate and consistent proportioning, the concrete was always produced by batch rather than by continuous mixers. Proportioning of the mixture was originally carried out by hand. The introduction of charging hoppers and aggregate measuring devices did not gain universal acceptance; the contract for Superior "C" specified that all proportioning was to be by hand. The type of mix varied; the concrete in Concrete-Central was wet mixed, while at Lake & Rail dry mixing was specified. The addition of water to the mix became more precise. In Concrete-Central it was to be of a "wet consistency"; in Lake & Rail water was added until the concrete had a "quakey consistency, soft enough to flow but dense enough to permit no separation of material"; and in Saskatchewan water was to be "sufficient for tamping into forms." By the mid-1930s, the amount of water to be added to a particular mixture was accurately determined by slump tests.[80] The Eastern States Elevator was to have "no more than 7 gallons of water per bag," while the Electric Annex was to have "water additions measured accurately to 1 gallon." Once mixed, the concrete was to be placed within twenty minutes.

Reinforcing bars were generally bent on-site using bar bending machines. In order to distinguish between differing grades of material, the bars were delivered to the site with distinctive deformation patterns. All bars required in the bins and superstructure were loaded on the working platform to be lifted with the forms. The carpenters prepared the forms while the foundation work was underway; a complete inventory of bars had to be taken before slip forming began.

As piling was completed, work could start on the parts of the elevator to be constructed by fixed forms.[81] In bin wall basement type, this would have amounted to little more that the foundation slab. In the pillared, walled or beamed basement elevator, all members up to and including the bin slab would have been constructed using fixed forms. The foundation slab, bin slab, columns and beams were poured to the full depth of the member in one operation.[82] Once placed, the concrete was agitated to expel air and eliminate any voids beneath the reinforcing bars and against the forms. The agitation could be manual by spading and puddling with rods or mechanical by shaking the reinforcing or vibrating the concrete. Eight to twelve hours had to elapse between lifts, and surfaces had to be grouted with mortar before the fresh concrete of the next lift could be placed. The fixed forms were not removed until the concrete was thoroughly set and able to support the live loads of construction. In the case of the Lake & Rail Elevator, the columns were not permitted to bear weight until five weeks after pouring.

Winter concreting was generally only carried out during fixed form basement work so that slip forming might commence with the spring. By the 1920s winter working methods were well-established. Sand and gravel was steam heated in the delivery hoppers prior to mixing. Mixing water was heated to between 40-90°F. After the concrete was placed, it was protected by tarpaulins and heated for at least four days.[83] The use of chloride solution to lower the freezing point of the mix does not appear to have been acceptable practice in Buffalo.

Once the bin slab or foundation slab was set, the bin arrangements would be marked out and the slip form work assembled. If the bin walls were to be of a uniform thickness, the forms were separated to suit. If they were to be thicker at the base, as in Superior "C", or Saskatchewan "A" and "B," or were to have pilasters, as in Marine "A", then the bin walls were set up to that thickness with fillers and chokers added to reduce wall thickness and to cut off the supply of concrete as necessary. Once in place, I-beams were set into the moving forms. Their principal function was to support the bin floor once the bins had reached full height, but during construction they served to support the working deck. The deck was raised with the forms and used as a means of distributing concrete from the elevating tower spout to the forms. It also carried all the reinforcing bars that were to be placed as the work proceeded.

When a workhouse was raised from the foundations, the forms for the structure were laid out and raised with the bin forms. If the workhouse incorporated its own set of rectangular bins, as in the Lake & Rail (1927) and GLF "A" (1941), the forms were arranged so that they might be used to produce columns and beams in the upper part of the structure. For workhouses utilizing divided main storage bins, Marine "A" and Standard for example, the forms for the part of the workhouse built above the main structure could only be assembled once the bin floor had been poured. When the elevator featured a headhouse, such as in the Saskatchewan (1925), the forms for this structure were only assembled once the bins had reached full height. These forms were also laid out so that they might be used to construct walls, bins, beams or pillars at the required position within the headhouse or workhouse.

The horizontal and vertical steel work was added to the depth of the first form and an initial lift of concrete poured. This concrete was allowed to harden in order to provide lateral stiffness for the jacking rods. The first series of jacking rods and verticals needed to be of at least two different lengths to ensure that subsequent joints were staggered. As several bars were required to produce the circumference of each horizontal bin band, they were also positioned to ensure the staggering of laps. The dimensions and precise position of all bars was usually laid down in the table of courses and verticals.

Slip forming began once the jacking rods were set firmly in the initial lift. The forms were raised continuously in increments of between 1/4" and 1" depending on setting conditions. A team of jack men was responsible for manning the jacks and assembling the sleeve-connected jacking rods. The efforts of the jack men were coordinated by whistle signals from the foreman. Sightings were taken twice a day to ensure that the lift of forms remained level.[84]

The concreting tower provided the datum for levels. All course heights were marked on this structure and projected over and marked on the jacking rods.[85] Where short jacking rods were used in conjunction with MacDonald jacks, a number of poles would extend from the bin bottoms and be calibrated in a similar fashion to the concreting tower.[86] The logistics of jacking at the Standard Elevator, raised at the rate of 11-12' per day in the 1928 season, might be considered typical. Each jackman was responsible for twelve jacks raised in 1/4" increments. In order to raise the forms at 6" per hour, the jackman had to make 288 turns per hour on his jacks. He responded to twenty-four whistle signals per hour, and with every signal he would apply a turn to each of his jacks.

As the forms rose, the iron men installed the reinforcing. The steel work was added within the forms, with only the jacking rods extending above the form work. The steel was placed in a carefully predetermined sequence ensuring that the joints in any one member were staggered in relation to neighboring members. The joints between the horizontal rods making up the bin bands were lapped to fifty times the diameter of the rod. The joints in the verticals were lapped to twenty-five times the rod diameter. The horizontals were fastened outside the verticals. All joints were made by wiring. Concrete was only poured in a particular area of form when the steel was in place. The concrete was placed in the form to depths of between 4" to 12" in a systematic fashion, so that it was laid in level lifts. The concrete was never spouted into the forms, as this often caused the components of the mix to separate. Rather, concrete was transported from the elevating tower hopper by man-powered "buggies" wheeled across the work floor. The concrete was poured directly from the buggies into the forms.

Mechanical agitation of the concrete in the forms was seldom used for fear of dislodging the partially set concrete below the forms. With the exception of the Lake & Rail Elevator, thorough spading of the concrete was the only permissible means by which it could be compacted in the forms. As soon as the forms were raised to a sufficient height, a working platform was suspended from them. Concrete finishers worked from the platform, smoothing the concrete with emery blocks as it emerged from the forms and repairing any breaks and voids in the walling.

In an elevator with a bin slab, the forms were stopped at a height of about 20' in order to place the hopper slab and fill within the bin.[87] The installation of the hoppers took from two to three days, after which slip forming resumed. Conversely, in bin-walled basement elevators, the ring girder and pillars were built by fixed form methods once the bin walls rose above ring girder level. In simple slip forming operations, the forms were raised to the top of the tanks and dismantled after a suitable time. A book tile floor was then constructed utilizing the beams that supported the working floor.

The casting of a concrete bin floor required a more complex operation.[88] The forms were stopped and the placing of concrete ceased within two feet of the bin floor. At this point, the inner and outer forms were bolted together so that the yokes, which would otherwise interrupt the pouring of the bin floor, could be removed. The working floor now became the lower fixed form for the bin floor, cornice forms were constructed and bin floor reinforcing added. Concreting resumed with the completion of the final 2' of bin wall and the addition of the monolithic bin slab.

Subtleties of technique were required when departures from the uninterrupted bin wall were specified.[89] Where apertures were required in the bin walling, as in the conveyor and personnel passages of bin wall basement elevators, chokers were placed in the form to temporarily block the flow of concrete to those areas. Once the forms reached the top of the apertures, a lintel form was placed between the inner and outer forms, but connected to neither. The lintel form was propped from below, and arrangements were made for bracing the jacking rods that passed through the aperture.

Similar techniques were employed in the workhouse or headhouse. To construct pillars, large areas of bin wall forms were choked off, the pillars being formed within the non-choked area that continued to receive concrete. Fillers were added inside the non-choked areas to reduce pillar dimensions at successively higher floor levels. The chokers were removed at particular levels in the structure to pour beams supporting floors or bases of hanging bins and garners.

The bottom form for the beam was placed between the inner and outer forms at the correct level. It was not attached to the slip forms, but was carried by timber struts resting on beams already poured for the floor below. Soft steel ties were inserted in the concrete above the beams in such a way that the forms could pass. The ties were later bent out to key in the floors or bin bottoms which were generally constructed after the completion of the slip forming. The slip-formed beams were provided with ties that supported the fixed forms for the flooring. If hanging bins or garners were constructed, the bin wall forms necessary to produce the required upper bin geometry were reactivated. As the headhouse/workhouse structure rose, it was possible to reduce its overall area by casting off forms, as in the Saskatchewan and Eastern States "A". A section of the moving forms was left behind, and a set of interior wall forms now produced the outside wall. The same procedures used to produce the bin floor were adopted to construct roofs at both full height and cast-off point. All curtain wall and bin wall windows were inserted within the forms at the appropriate level, positioned either inside or outside any impeding jacking rods. To ensure that they remained in location as the forms passed, the windows were fastened to stud bars incorporated into the concrete below.

The 1-million-bushel Eastern States Mainhouse built during the 1934 season is representative of construction practice. At this particular site, ground preparation was simplified by the presence of load-bearing clay that required no piling. At most of the Buffalo River sites, piling work could take up much of the winter. The plans were worked up during the winter and early spring in preparation for the commencement of construction as the weather improved.

By March 23, 1934, the site was being cleared for the placing of the foundation slab, and, by April 11, half of the slab had been poured. Concrete was not mixed in an on-site plant but supplied ready-mixed by truck. The foundation slab was completed by April 18, and work began on form construction, a job that was to take about five weeks to complete. By this date, a complete set of form hoops had been delivered from the carpenter's shop, and, by May 2, all the forms were assembled and in place with the vertical staves added to the form hoops. Also during this period, the concreting tower was completed to the full height of the bin floor. By May 15, 1934, all the yokes and jacks had been added to the forms, the bin floor I-beams installed across the forms, and the working platform built across these beams. The working platform spouting arrangements were also complete.

Following the completion of the form work, about a week of additional work was necessary before slip forming could begin. By May 23, the first tier of vertical steel and jacking rods was in place and set in the first lift of concrete. All the props and lintels had been installed to support the areas of the basement bin walling where there were to be apertures. The working platform had been equipped with a full set of lights to facilitate continuous pouring and loaded with all bars necessary for subsequent construction. Slip forming could now proceed.

Twenty feet of wall had been constructed by May 31 and the concrete finishers' platform suspended below the forms. Sixty-five feet of wall was complete by June 6, at construction rates of between 7' and 8' per day; three weeks later, the bins were at full height and the bin floor under construction. The forms were still in place but the yokes had been removed to facilitate the placing of the bin floor. By July 6, the bin floor was complete and all slip and bin floor forms removed. The workhouse forms had been modified for their upward progress during the construction of the remainder of the workhouse. An additional concreting tower had been added on the working platform of these forms. By July 15, 15' of the upper workhouse had been slip formed, and two weeks later, the structure had reached its full height. This complex process, including the installation of four sets of floor beams and concrete garner bins and the cutting off of forms at the various roof levels, took about three weeks.

With the completion of the concreting, work proceeded on the steelwork of the gallery and railroad shed throughout August. Simultaneously, the plant was being installed in the elevator. By mid-September, the gallery belts and trippers were in place, to be followed later in the month by the bin hoppers. All the workhouse spouting and elevating equipment appears to have been installed by early October and from this date would have been operational. The total construction time amounted to about five months.

Approximately 250 men were employed in the construction of a typical 2-million-bushel elevator. They were divided into night and day shifts. On each shift, seventy-five were employed as workers on the deck, thirty-five in distributing and placing concrete including buggie wheelers, shoveller and spaders, eighteen as jackmen raising the forms, ten as ironworkers setting and tying the reinforcing, five as laborers supplying steel to the ironworkers and four as concrete finishers, with three helpers working from the hanging scaffolding. The remaining employees were ground workers involved in the handling and mixing of materials and carpenters engaged in form construction and modification both in their shop and on the working deck.[90]

In the case of the storage bins, 25 percent of the total costs were accounted for by the cement, 13 percent by the reinforcing steel, 9 percent by the aggregate, and 4 percent by the forms. The labor costs amounted to 41 percent of the total cost; the construction of the form work, 11 percent of the total, was followed by 10 percent for placing concrete, 10 percent for jacking, and 4 and 3 percent respectively for the placing of steel and mixing of concrete. In the workhouse, 26 percent of the total cost was accounted for by the reinforcing steel, 13 percent by the cement, 5 percent by the aggregate, and 3 percent by the form timber. Labor costs represented 39 percent of the total cost, with the jacking the most expensive item at 15 percent of the total. The construction of the forms and the placing of the concrete followed at 9 percent each of the total expenditure, with the placing of the steel representing 8 percent of the costs and the mixing of the concrete 2 percent.[91]

CONCLUSION

The concrete elevator, the culmination of the search for the most suitable and economical means of handling and storing grain, represents a continuous process of development from wooden, steel and tile elevators. During the era of the wooden elevator, the logistics of bin and machinery arrangements were developed to a state requiring little subsequent modification. The structural properties of steel and steel-reinforced tile conferred new freedom upon the elevator engineer to experiment with bin dimensions and bin arrangements. The superiority of the cylindrical bin for large volume storage was established. The legacy of this era provided the engineer of the concrete elevator with an inventory of basic bin geometries. The concept of the interspace bin, created between main bins in tangential contact or spread with connecting link walls; the outerspace bin with either straight or curved walls; and the interlocking main bin had all been established before the era of the concrete elevator.

The increasing scientific curiosity accompanying the search for a suitable fireproof material for grain storage produced a body of engineering knowledge that was to prove valid throughout the period of concrete grain elevator construction in Buffalo. The fundamental laws of the behavior of grain at rest and in motion in deep bins were established around the turn of the century. The flexibility inherent in concrete construction allowed the elevator engineer to alter readily the dimensions and arrangement of bins in an attempt to achieve the most suitable variety of storage volumes for a given application with the greatest economy of material within the constraints of a particular site.

Concrete was applied progressively and selectively to the various parts of the elevator. By the 1890s, wooden elevators were being constructed on concrete foundations and fitted with concrete floors. The iron elevator was usually constructed on concrete foundations and, by the turn of the century, invariably featured a sophisticated full basement of reinforced concrete. The era of the true concrete elevator is defined by the application of reinforced concrete to the construction of storage bins. Once the structural integrity, suitability and cost advantages of the material were proven, this application quickly superseded all others.

Although the elevator with concrete bins was ascendant within ten years of Haglin's pioneering structure of 1899, the part of the elevator above the bins was a hybrid for the next decade. The book tile bin floor inherited from the tile elevator was common throughout that time, but the gallery and headhouse were more likely to be of structural steel than concrete. The economical application of slip forming techniques to the complexities of headhouse and workhouse construction developed from the early 1920s. Buffalo's legacy of large all-concrete elevators dates from this period.

Despite a significant sample of bins, establishing trends in size and arrangement is problematic. Limitations of bin building technology are perhaps the factor of least significance. Haglin's experimental bin was 124' high, and early elevators tended to have bin heights of 80' to 90' with diameters of 20' to 25'. Buffalo's 160' high single bin, built in 1912, was not slip formed, a possible indication that slip forming such tall structures was impractical in the early years of the technology.

It seems logical that any trends in bin dimensioning reflected the elevator designer's wish to achieve the most economical solution to particular storage problems. The nature of a problem did not always dictate that bins should be built to maximum dimensions. For example, the Kellogg Elevator was built to serve the New York Barge Canal, and its main bins were designed to store the capacity of one barge. The Dellwood "C" Elevator was designed to fulfill a similar function, its unusual subdivision of space reflecting the need for a large number of bins of varying capacity. The Eastern States Elevator and GLF "A" & "C" elevators were built to serve feed mills. Their relatively small bin dimensions reflect the need to store numerous types and qualities of component materials. The exceptionally tall 150' bins of the Lake & Rail Northwest Annex were apparently required to maximize storage capacity on an extremely confined site. The 125' bins of the H-O Oats Elevator (1931) occupied an equally restricted site.

A comparison of elevator styles and bin dimensions of transfer elevators reveals a clearer picture of trends in bin size. The earliest elevators were of the tunnel type. Although constructed at the end of the elevator building era, the dimensions of the tunnel style are similar to those of the tunnel type elevators constructed during the first decade of the century. For example, the Connecting Terminal Annex is 107' x 30', and the central bins of the Electric Annex are 90' x 30'. The advent of the full basement elevator with bins supported on a network of hopper (basement) beams elevated on pillars appears to coincide with a reduction in bin size. The American and Perot elevators have bins of 90' x 26'-4". The bins of the Wheeler measure 90' x 25' and those of the Kellogg, 85' x 26'-8".

The reduction in bin size reflects the high loadings on the basement pillars and the difficulty in dealing with imbalance between the loads of adjacent bins of greater capacity. The introduction of the walled basement type elevator with bin slab, marked by a noticeable increase in the average dimensions of bins, may reflect the increased capacity of the bin slab and walling to deal with the cantilever action between bins holding differing volumes of grain. The Washburn Crosby "C1" has bins of 107' x 32', and its "C2" and "C3" bins measure 116'-6" x 31' and 116' x 22' respectively.

The substitution of pillars or columns for basement walling in bin slab type elevators coincides with a marked reduction in the dimension of bins. The series of elevators designed by Wait and Howe have average bin dimensions of 90' x 20', though the latter examples increase in height to 125' at the American Annex and H-O Oats. The Lake & Rail Elevator (1927) is built in a similar style and has bins of 110' x 23'-2", confirming the progressive increase in the bin height of this type of elevator. The reduction in the diameter of the bins possibly reflects the necessity of distributing bin wall loads evenly to equidistantly spaced columns. Such spacing was best attained by spread bins; however, spread bins above 24' in diameter required disproportionate additions of material to counter bending moments in the bin walls. The introduction of the bin wall basement elevator coincides with a marked increase in bin sizes, as loads are again transferred directly to the foundation slab.

Changes in bin arrangements often mirror variations in elevator styles. Tunnel type elevators generally have bins in tangential contact and do not feature outerspace bins. Basement elevators with hopper beams and pillars have bins in tangential contact and relatively small outerspace bins. Basement wall bin slab type conveyors have bins in tangential contact but lack outerspace bins. Basement pillar/column bin slab style elevators invariably have spread bins and feature outerspace bins. Bin wall basement type elevators have bins in tangential contact or slightly spread in one direction and usually lack outerspace bins.

Throughout the twentieth century, the design of reinforcing, proportioning of walls and the alteration of mixes became more sophisticated. Early elevators such as American, Perot and Kellogg had very small graduations of horizontal bar. Later such small graduations were standardized to a few horizontal bar sizes, as in Concrete-Central. The substitution of round bar for rectangular and square bar in the 1920s coincided with increasingly sophisticated coursing of horizontals and with the introduction of variable rather than constant course intervals, as in Saskatchewan, Lake & Rail and Standard Annex. As the era of elevator construction ended, designs once more reverted to simpler forms like Connecting Terminal Annex. The alteration of the mixes in the bin walls became a feature of elevator construction from the mid-1920s; the distribution of verticals was increasingly selective, and their density was reduced in interior walls.

The changes in basement arrangements were the primary limiting factors in the determination of economical bin dimensions and configurations. The nature of the basement arrangements affected the proportion of the total weight of the elevator used for storage. The absolute load and its distribution determined the magnitude of foundation works. Once the tunnel elevator had been abandoned for most large transfer elevators, foundation works had to increase substantially to deal with the additional load of basement works. Subsequent developments aimed to increase the proportion of total structural weight used for storage while retaining the convenience of a basement. Budd's bin wall basement designs most closely approached this ideal. However, the data for costs and loadings reveals few trends to confirm the economy of this design.

Architectural elaboration was minimal during the entire era of elevator construction in Buffalo. Early elevators like the Kellogg (1910) and Wheeler (1909) featured rusticated basement panels. Connecting Terminal (1914) was the last elevator to feature such elaboration. The elevators of C. D. Howe, such as Saskatchewan (1925), featured characteristic concrete headhouses pierced by continuous elongated International Style windows. In elevators like Perot Annex (1933), H. R. Wait adopted a similar style, repositioning basement pillars so that the basement walls might feature such windows. A. E. Baxter's elevators used functional features to create architectural detail. The piers of workhouse walls were exposed on the external walls of Standard (1928). The bin floor formed an overhanging eave to the bin tops, while structural gallery and bin floor beams were exposed to form corbel detailing.

TABLES

TABLE 1

ELEVATOR	DATE	CAPACITY bushels	COST dollars	UNIT COST cents/ bushel
		IRON ELEVATORS		
Great Northern	1897	2,350,000	400,000	17
Electric	1897	1,000,000	150,000	15
Great Eastern	1901	2,500,000	500,000	20
Dakota	1901	1,250,000	250,000	20
J. Kam Malting	1901	550,000	150,000	27
Iron	1902	500,000	100,000	20
Monarch	1905	450,000	200,000	31
Monarch Extension	post 1912	c.300,000	-	-
Electric Extension	pre 1913	750,000	-	-
Cloverleaf Milling	post 1915	100,000	-	-
		CONCRETE ELEVATORS		
American	1906	2,250,000	400,000	17
Perot	1907	500,000	-	-
Ralston Purina	1907	500,000	150,000	14
Riverside Malt.	1907	200,000	-	-
Coop. GLF	1908	700,000	148,000	21
Washburn Crosby B	1909	250,000	-	-
Washburn Crosby C1	1909	750,000	125,000	16
Spencer Kellogg	1910	1,000,000	225,000	22

TABLE 1 (continued)

ELEVATOR	DATE	CAPACITY bushels	COST dollars	UNIT COST cents/ bushel
Buffalo Cereal	1910	150,000	-	-
Washburn Crosby C2	1913	2,388,100	200,000	8
Meyer Malting	1913	261,000	-	-
Connecting Term.	1914	1,048,000	227,000	21
Dellwood A	1914	264,000	-	-
Superior A	1915	1,500,000	317,800	21
Concrete-Central A	1915	1,050,000	226,700	21
Dellwood B	1916	600,000	111,150	18
Concrete-Central B	1916	950,000	176,000	18
Concrete-Central C/D/E	1917	2,500,000	475,000	19
Ralston Purina Annex	1920?	300,000	-	-
Dellwood C	1922	635,000	200,000	31
Superior B	1923	1,100,000	275,000	25
Superior C	1925	1,100,000	250,000	22
Marine A	1925	2,042,208	510,500	25
Saskatchewan A	1925	1,100,000	800,000	72*
Washburn Crosby C3	1925	1,200,000	225,000	18
Saskatchewan B	1926	900,000	300,000	33
Lake & Rail Mainhouse	1927	1,600,000	300,000	18
Standard A	1928	3,000,000	450,000	15

TABLE 1 (continued)

ELEVATOR	DATE	CAPACITY bushels	COST dollars	UNIT COST cents/ bushel
Lake & Rail N. Annex	1928	650,000	100,000	15
Lake & Rail S. & S.W. Annexes	1928	1,000,000	250,000	25
Pratt Foods	1929	210,000	-	-
Lake & Rail N.W. Annex	1930	1,150,000	220,000	19
HO Oats	1931	600,000	-	-
American Annex	1931	1,400,000	-	-
Perot Annex	1933	431,000	-	-
Eastern States Mainhouse	1934	1,013,000	-	-
GLF C	1936	170,000	50,000	29
GLF A	1941	1,000,000	900,000	90
Standard B	1941	2,000,000	275,000	13
Electric Annex	1941	6,000,000	480,000	8
Eastern States Annex	1946	1,314,000	-	-
Connecting Terminal Annex	1954	600,000	400,000	66

NOTES

DATES are derived from the building permit records of the City of Buffalo. Where a permit was issued towards the end of a year the following year appears in the table, to reflect the building season during which construction would have taken place; Where several elevators were built in one year they are tabulated in chronological order according to the date of issue of the permit.

CAPACITIES have been generated from a number of sources. Preference has been given to capacities appearing on original plans, and contracts, in their absence figures appearing in contemporary trade journals, and fire insurance documents have been used.

COST: The City Plan's Books contain details of the estimated costs of construction. These documents provide the best record of likely contract prices, and where costs of construction are given in trade journals they appear comparable.

* The cost given for Saskatchewan "A" appears to reflect the additional expense of reclaiming the lake shore for both "A" and "B" Houses.

TABLE 2

ELEVATOR	TYPE	DATE	NUMBER PILES	BUSHELS /PILE
Coop. GLF	Separate Basement, Hopper Beams	1908	1400	500
Wash. Crosby C1	Separate Basement, Walled, Bin Slab	1909	1750	428
Spencer Kell.	Separate Basement, Hopper beams, Bin Slab	1910	2160	462
Wash. Crosby C2	Separate Basement, Walled, Bin Slab	1913	6400	373
Superior A	Separate Basement, Columned, Bin Slab	1915	3300	454
Concrete-Cent.	Separate Basement, Columned, Bin Slab	1915	11700	383
Superior B	Separate Basement, Columned, Bin Slab	1923	2000	550
Saskatchewan	Separate Basement, Columned, Bin Slab	1925	2780	395
Superior	Bin Wall Basement, Ring Girder, Radial Columns	1925	2260	486
GLF C	Bin Wall Basement, Ring Girder, Radial Columns	1936	515	330
Electric Annex	Storage Hall	1941	2500	2400
Connect. Term.	Tunnel	1954	500	1200

NOTE: The piling details have been derived from original plans. Where plans were insufficiently complete to allow direct counting, figures have been extrapolated from available information. e.g. where plans show only the arrangements beneath a typical column, then a figure has been derived as a product of summing all such columns.

ENDNOTES

1. Prior to 1970 the urban area of today's Thunder Bay was known as Port Arthur and Fort William.

2. Le Corbusier, Towards A New Architecture (1927), in Reyner Banham, A Concrete Atlantis (Cambridge, Mass.: MIT Press, 1986), 224.

3. "The Elevators of Buffalo," Buffalo Courier (2 May 1894), provides details and illustrations of contemporary elevators, including the Coatsworth and Eastern.

4. "A Great Elevator Enterprise," Buffalo Express (November 7, 1886), provides details of the Lake Shore Elevator among others.

5. Details of wooden construction are given by J. MacDonald in Journal of the Western Society of Engineers, 7 (1901), and Boller in Journal of the Franklin Institute, 7 (1866).

6. Details of telescopic joints are given by L. J. McMillen in Grain Dealers Journal, Special Plans Book 3 (1913): 369; Robinson's rope drives, patented in 1892, attempted to solve this problem, as did those patented by Heidenreich in 1890.

7. Details of the construction of the Husted Elevator designed by J. MacDonald appear in American Elevator & Grain Trade, 19 (15 December 1900): 251.

8. The Export Elevator is illustrated in American Elevator & Grain Trade 19 (15 November 1900): 212.

9. Details of early iron and steel elevators are given by J. MacDonald in the Journal of the Western Society of Engineers, 7 (1901), and Kennedy in Engineering News (14 July 1901).

10. The Plympton Elevator does not appear in the Buffalo Exchange Records of 1894.

11. Details of insurance premiums and finances are from A. C. Olds, "Grain Elevator Construction," Insurance Engineer 10 (1909), J. Kennedy, Engineering News (17 July 1909) and A. J. Curtis Concrete (June, 1921).

12. The City Plans Book for 1897 gives the estimated construction costs of the two phases of the Export Elevator (approved April 17, 1897 and October 18, 1897) as $130,000. See J. Kennedy, "Fireproof Grain Elevators in America," Engineering News (18 July 1901): 43 and R. H. Folwell, "A Steel Structure," Northwestern

Miller 45 (4 February 1898): 175.

13. Both J. MacDonald, "Fireproof Grain Elevator Construction," Journal of the Western Society of Engineers, 7 (1901): 36 and J. Kennedy, "Fireproof Grain Elevators in America," Engineering News (18 July 1901): 43 relate the advantages of iron and conclude it to be the most suitable material for grain elevator construction.

14. The Electric is described in Engineering News (17 March 1898): 171.

15. The Great Northern is described in Engineering News (4 April 1898): 218.

16. This system was patented by Toltz and Robinson June 12, 1897.

17. R. H. Folwell, "A Steel Structure," Northwestern Miller 45 (4 February 1898): 175, describes the efficiency of land use of various bin arrangements.

18. A description of Great Eastern noting the novelty of concrete basement works appears in the Buffalo Express, 31 March 1901.

19. Details of concrete work applied to the foundations and basements of steel elevators are provided by B. I. Weller in "Concrete Elevators," Grain Dealers Journal, Special Plans Book 3 (1913): 372.

20. Cohen held a patent on this style of bin construction dated March 20, 1903. The James Stewart Company constructed elevators to a very similar pattern, but none are thought to have been built in Buffalo. Fallis held a patent (July 31, 1894) on a hexagonal bin system in steel; it is unknown whether any elevators were built to this pattern.

21. Construction costs appear in J. MacDonald, "Fireproof Grain Elevator Construction," Journal of the Western Society of Engineers 7 (1901): 36.

22. Construction costs are derived from city records. See Table 1.

23. In "Concrete Elevators," Grain Dealers Journal, Special Plans Book 3 (1913): 372, B. I. Weller states that tile "has been used for a number of years, and even now and then elevators are built of it."

24. E. V. Johnson's bins were patented October 16, 1899; May 31, 1900; and June 4, 1900. The Barnett Record Company took out its own patent April 20, 1903.

25. The relative advantages and disadvantages of tile elevators are given by B. I. Weller in "Concrete Elevators," Grain Dealers Journal, Special Plans Book 3 (1913): 372.

26. The facilities at the Maritime Milling Plant are described in American Elevator and Grain Trade, 39 (15 June 1922): 920.

27. The maximum capacity for wooden bins and other limitations are given by H. H. Broughton in "The Handling & Storage of Grain, with Special Reference to Canadian Methods," in Proceedings of the Institute of Mechanical Engineers (January 1933): 69.

28. Details of experimental work on the behavior of grain may be found in Milo Ketchum, "Chapter XVII," The Design of Walls, Bins and Grain Elevators (New York: McGraw-Hill, 1913).

29. The pressure changes experienced during unloading are summarized in "Increase in Pressure of Grain While Being Emptied," Grain Dealers Journal, Special Plans Book 1 (1904).

30. The advantages of reinforced concrete elevators are given by B. I. Weller in "Concrete Elevators," Grain Dealers Journal, Special Plans Book 3 (1913); J. F. Ryan, "Concrete for the Small Country Elevator," Northwestern Miller (28 February 1929): 775; J. Spelman, "The Evolution of Modern Elevator Construction," Contract Record (23 September 1914): 1182; R. P. Durham, "Concrete Grain Elevator Construction," Concrete & Cement Age (January 1913): 41.

31. An account of the Weavers Mill Silos of 1897, at Swansea, Wales, and details of the Silverton and Dunston silos may be found in Ferro-Concrete (1909).

32. The advantages of reinforced concrete elevators are given by B. I. Weller in "Concrete Elevators," Grain Dealers Journal, Special Plans Book 3 (1913): 372; J. F. Ryan, Northwestern Miller (28 February 1929); J. Spelman, "The Evolution of Modern Elevator Construction," Contract Record (23 September 1914): 1182; R. P. Durham, "Concrete Grain Elevator Construction," Concrete & Cement Age (January 1913): 41.

33. The advantages of the cylindrical form are explained by J. H. McCoy in "Why Should Silos Be Round?," Concrete & Cement Age (May 1911): 245.

34. The maximum economical size for a square bin is quoted as 10-12" by L. B. Mercer in "Some Basic Principles of Grain Elevator Design," Engineering News Record (19 July 1934). H. H. Broughton gives a figure of 12" in "The Handling & Storing of Grain, with Special Reference to Canadian Methods," Proceedings of the

Institute of Mechanical Engineers (January 1933): 69, and A. E. MacDonald quotes 15" in "Grain Elevator Design & Construction, Part 6," Contract Record & Engineering Review (13 March 1929).

35. A. J. Curtis and C. D. Gilbert give detailed comparative accounts of the materials requirements for cylindrical and square bins in Concrete (June 1921) and Concrete & Cement Age (August 1912). The relative disadvantage of the square bin may be illustrated by the materials required for 50' deep cylindrical and square bins of varying dimensions.

36. A. E. MacDonald details the engineering of bin walls for compressive forces in "Grain Elevator Design & Construction," Contract Record & Engineering Review (23 January 1929): 78.

37. Details of the tensile forces in the bin walls are given by W. H. Hay, "Design of Circular Reinforced Concrete Bins," Concrete (September 1920): 73 and "Design of Deep Circular Bins," Concrete & Cement Age (March 1913): 129. See also B. M. Mathias, "Construction of Grain Elevators," Concrete (April 1917): 169.

38. For an explanation of steel requirements see A. E. MacDonald, Contract Record & Engineering Review (23 January 1929).

39. W. H. Hay explains this method of applying the horizontal reinforcing in Concrete (June 1928).

40. Details from engineering calculations for the Kellogg Elevator (1909) and Connecting Terminal Annex (1954).

41. Accounts of early reinforcing systems may be found in Milo S. Ketchum, The Design of Walls, Bins and Grain Elevators (1907 edition). The Metcalf spiral system used on the Santa Fe Elevator is described on pp. 340-345. The round rod system used by Metcalf at the Missouri Pacific Elevator is described on p. 305. The more conventional system used by the Barnett Record Company at the Canadian Pacific Elevator is to be found on p. 347. Ketchum also gives a description of the design and calculation of the horizontal and vertical reinforcing steel of a cylindrical concrete bin on pp. 302-304.

42. The function of vertical reinforcing is explained by R. H. Folwell and R. P. Durham in "The Development of Methods of Raising Slip Forms Used in Forming Concrete Bins," Grain Dealers Journal, Special Plans Book 5 (1942): 6.

43. Durham explains some of the early problems with slip forming, particularly the suitability of the cement.

44. Details of the proportioning of forms and the distribution of jacking rods are provided by McKay in "Details of Movable Forms & Their Operation," Concrete (April 1931).

45.Hennebique's construction methods and philosophy are described in Ferro-Concrete (1909).

46. An account of elliptically walled square bins in Ferro-Concrete 2 (1915) describes the elevator at Odsall Dock, Manchester, England.

47. J. A. Jamieson's square bins are described in Milo Ketchum, The Design of Walls, Bins and Grain Elevators (1907), pp. 232-33.

48. A. E. MacDonald explains the proportioning of link walls in "Grain Elevator Design & Construction, Part 4," Contract Record & Engineering Review (13 February 1929): 167.

49. Details of experimental loadings on 18' concrete bins appear in Engineering News, Vol. 84, p. 317.

50. Movement and thrust diagrams for various bin configurations are provided by H. H. Frenzel in "Design Notes on Circular Concrete Bins for Grain Storage," Engineering News Record (September 1932): 291.

48. L. B. Mercer gives a good description of the forces within a tunnel type elevator in "Some Basic Principles of Grain Elevator Design," Engineering News Record (19 July 1934).

49. Details of the design of a basement wall elevator are provided by W. H. Hay in "Design of Circular Reinforced Concrete Bins," Concrete (September 1920): 73.

50. H. A. MacDonald states that no pile should be loaded beyond 25 tons. See "Grain Elevator Design & Construction, Part 5," Contract Record & Engineering Review (20 February 1929): 167.

51. The mechanical action of the slab is described in Engineering News Record (9 April 1947): 85.

52. Data calculated from original engineering calculations for Washburn Crosby "C2" (1913), Saskatchewan "A" (1925), and GLF "C" (1936) is held in Buffalo City Hall.

53. The action of the bin wall basement type conveyor is described in T. D. Budd's patent of September 20, 1921 (No. 1,391,279).

54. H. A. MacDonald explains the importance of completing the workhouse in "Grain Elevator Design & Construction, Part 5," Contract Record & Engineering Review (20 February 1920): 167.

55. The date at which slip forming was applied to headhouse and workhouse is unclear. R. P. Durham implies that such structures were constructed using fixed form methods and indicates their novelty. He quotes the example of the Montreal Harbor Commissioners Elevator (1910). See "Concrete Grain Elevator Construction," Concrete & Cement Age, (January 1913): 41. B. I. Weller recommends a limited use of slip form techniques in "Concrete Elevators," Grain Dealers Journal, Special Plans Book 3 (1913): 372. However, H. A. MacDonald implies that widespread adoption of the techniques was only relatively recent in "Grain Elevator Design & Construction," Contract Record & Engineering Review (20 February 1929): 167. H. H. Broughton confirms this view, stating of the workhouse "to its design a good deal of attention has been given in recent years." See Broughton, "The Handling & Storing of Grain, with Special Reference to Canadian Methods," The Proceedings of the Institute of Mechanical Engineers (January 1933): 69.

56. This workhouse is described in American Elevator and Grain Trade 26 (15 June 1908): 638.

57. S. C. Clark describes these trends in confining fire damage in Grain Dealers Journal, Special Plans Book 5 (1942).

58. American and European construction rates are compared in J. Spelman, "The Evolution of Modern Elevator Construction," Contract Record (23 September 1914): 1182.

59. Details of the evolution of slip forming methods are given by R. H. Folwell and R. P. Durham in "The Development of Methods of Raising Slip Forms Used in Forming Concrete Bins," Grain Dealers Journal, Special Plans Book 5 (1942) and Durham, Concrete & Cement Age (January 1913): 41. The accounts are slightly at variance.

60. The system was patented November 20, 1900.

61. Various shifting panel techniques are mentioned by C. D. Gilbert in "Building Concrete Silos--Monolithic Construction, Types of Commercial Equipment," Concrete & Cement Age (August 1915): 58. Blaw steel forms appear in Concrete & Cement Age (October 1912): 103 and "Concrete Elevator Built with Steel Forms," Concrete & Cement Age (November 1916): 151.

62. The Metcalf jacking system is described in Concrete & Cement Age (March 1913): 128.

63. Personal conversation with Mr. Ed Hennessey, formerly of the Monarch Engineering Company.

64. Durham, Concrete & Cement Age (January 1913), suggests that the lack of such rapid-setting cements in Europe retarded the development of slip-forming construction there.

65. A. D. Whipple gives a figure of 5' per day in "Field Notes on the Construction of a Great Concrete Standpipe," Concrete & Cement Age (February 1911): 53.

66. The Buffalo Live Wire (1909) gives a figure of 4' per day.

67. The arrangement of jacks is described by McKay in "Details of Movable Forms & Their Operation," Concrete (April 1931).

68. McKay, Concrete (April 1931).

69. Engineering News Record (4 September 1947).

70. The design of formwork is detailed by McKay in Concrete (April 1931).

71. The use of flexible joints is noted by J. M. Skinner in "Mammoth Concrete Storage Tanks Built with Slip Forms," Concrete (January 1927): 17.

72. European handling methods are described by R. A. Sidley in "The Equipment of Silo Granaries," The Electrician (10 January 1919): 68.

73. The first slip-formed structure appears to have been the Port of London, Nut Silos, built in 1917 and described in Concrete Construction & Engineering (June 1917). These were cylindrical structures. The first application of slip forming to square bins was probably King Georges Dock Elevator, Hull, England, built in 1919 and described in Concrete Construction & Engineering (February 1920).

74. European shifting panel techniques are described by Heidenrich in Concrete (December 1921): 234-35 and in the report on the 1928 construction of Cranfield's Elevator at Ipswich, England, in Concrete Construction & Engineering (August 1928). Heidenbreich's account of the construction of the Nakskov Silos in Denmark details the wall stress calculations.

75. The "world record" rate of construction of the Royal Victoria Dock Elevator, London, is described in Concrete Construction Review (1933).

76. Piling methods at GLF "A" are featured in Engineering News Record (20 November 1941).

77. Details are contained in the contract for Saskatchewan Elevator (1925).

78. Details are contained in the contract for Lake & Rail Elevator, (1927).

79. Details are contained in the contract for GLF "A" (1941).

80. On-site laboratory testing of water ratios is noted in "Water Ratio on Grain Elevator Job," Concrete (November 1926).

81. Fixed form work is described in an account of the construction of Grand Trunk Pacific Elevator in Grain Dealers Journal, Special Plans Book 3 (1908).

82. Personal conversation with Mr. Henry Baxter, formerly of A. E. Baxter Engineering Company.

83. "That Winter Job," Concrete (October 1926), details current practice.

84. H. A. MacDonald recommends 4" lifts of concrete in "Grain Elevator Design & Construction, Part 6," Contract Record & Engineering Review (13 March 1929).

85. Details of jacking operations are taken from Henry Baxter, "Grain Elevators," Adventures in Western New York History, Vol. 26, p. 12.

86. The contract for Concrete-Central (1915) specifies 12" lifts.

87. A. E. MacDonald details this operation in "Grain Elevator Design & Construction, Part 5," Contract Record & Engineering Review (20 February 1929): 167.

88. The operation of pouring a monolithic bin floor is described by J. M. Skinner in "Mammoth Concrete Storage Tanks Built with Slip Forms," Concrete (January 1927): 17.

89. Complex slip-forming operations in workhouses are described by H. H. Broughton in "The Handling & Storing of Grain, with Special Reference to Canadian Methods," Proceedings of the Institute of Mechanical Engineers (January 1933): 69, and by J. M. Skinner in "Mammoth Concrete Storage Tanks Built with Slip Forms," Concrete (January 1927): 17.

90. Deployment of labor in elevator construction is given in "Improved Concreting Techniques Facilitate Grain Elevator Construction," Engineering News Record (4 September 1947): 88.

91. Costs of elevator construction are given by H. H. Broughton in "The Handling & Storing of Grain, with Special Reference to Canadian Methods," Proceedings of the Institute of Mechanical Engineers (January 1933): 69.

APPENDIX

CLOVERLEAF MILLING CO. ELEVATOR
(Eastern States Farmers Exchange)

Status:	Demolished in 1934 after construction of Eastern States Farmers Exchange Mainhouse
Date:	1915 (?)
Designer:	-
Foundations:	Spread footings
Basement:	Tunnel type
Bins:	Total capacity of 100,000 bushels; 3 steel bins, free standing and divided by radial walls into sectors having their outlets near the sector apexes; method of constructing sector walls unknown
Gallery:	Open

REFERENCES: A. E. Baxter plot plans and photographs; Henry H. Baxter, personal communication, 31 July 1992.

DAKOTA ELEVATOR
(Lehigh Railroad Elevator)

Status:	Demolished mid-1965
Date:	Building permit filed December 2, 1900; approved December 27, 1900; tanks and cladding complete and cupola under construction by July, 1901
Designer:	Ballou and Shirley
Builder:	Eagle Ironworks, Buffalo
Cost:	$250,000
Foundation:	Wooden piles
Basement:	Full height, bins supported on steel columns
Bins:	Capacity 1,250,000 bushels 64 cylindrical main bins of 15'-6" arranged on 16'-6" centers; 4 x 16 parallel, non-interlocking rows; 70' high; 10,500 bushel capacity Interspace bins: 45 between slightly spread main bins; 5,000 bushel capacity Outerspace bins: 36, outer wall formed of pressed-steel plates featuring a contoured depression for additional rigidity
Cupola:	Full height, 4-story, along length of structure Structural steel clad in corrugated iron Pitched roof with monitor

REFERENCES: Plans in Buffalo City Hall could not be found. Engineering News (18 July 1901): 42, reviews several elevator construction projects including the Dakota, referred to as the Lehigh Railroad Elevator. The arrangement and shape of the bins can be deduced from a photograph of the elevator under construction in the Buffalo News of October 13, 1901. Extrapolation from this source suggests that there were 145 bins. However, the Sanborn Fire Insurance Map gives a figure of 153, the difference perhaps accounted for by divided bins. The Dakota occupied the site of the Sturges Elevator which burned down in 1897. Buffalo News reports of January 9, 1898, and February 3, 1898, suggest that the Eagle Iron Works was about to build a steel elevator on the site. It is not known why the project was delayed for three years or if the Eagle Iron Works did finally undertake the project. The design bears some resemblance to that patented by the Buffalo designers Ballou and Shirley, particularly with respect to the outer walling. The date of their application for patent rights coincides with the beginning of the elevator's construction.

DELLWOOD ELEVATOR

ELEVATOR "A"

Status: Demolished

Date: 1914

Designer: Unknown

Builder: Unknown

Cost: Unknown

Bins: Capacity 264,000 bushels
3 x 3 cylindrical bins, all of similar radius; four corner and single central bin full cylinders 35' in diameter; intermediate outer bins almost full cylinders forming large outerspace bins; link walls provided by walls of central bin height 93'

Workhouse/
Marine Tower: Structural steel clad in corrugated iron

REFERENCES: The original plans filed in Buffalo City Hall have been lost. Sanborn Fire Insurance maps provide the only source of information.

ELEVATOR "B"

Status: Demolished

Date: Building permit application January 21, 1916; approved May 17, 1916

Designer: H. R. Wait

Builder: Monarch Engineering Company

Cost: $111,150

Foundation: Wooden piles capped by 2' foundation slab thinning to 6" below centers of main and interspace bins

Basement:	Tunnel variant, 7' high; tunnel above foundation slab and enclosed by longitudinal walls and 12" bin slab; tunnel subdivided by discontinuous central longitudinal wall with integral pillars located beneath link walls
Hopper:	Mortar hopper slab on slag concrete, resting directly on foundation slab; draw-off through side of tunnel wall via three spouts to each bin and through bin slab via three more spouts per bin
Bins:	Capacity 800,000 bushels Main Bins 9 x 2 in parallel rows, cylindrical 25' in diameter on 30' centers; 70' high (from foundation slab) Interspace bins 8 x 1 No outerspace bins Non-tangential link wall contacts between bins; link walls 3'-6" x 2' Bin wall thickness 8" Vertical reinforcing unknown Horizontal reinforcing of square bar; bars graduated with height; course intervals vary with height, frequency of courses decreases with height; link walls reinforced with 1/2" bars for their entire height and follow coursing intervals of main bins
Bin Floor:	Book tiles supported by I-beams
Gallery/ Workhouse:	Structural steel clad in corrugated iron

REFERENCES: The original plans in Buffalo City Hall provide much of the above information. City building permits provide dates and City Plans Book for 1915 the cost of construction.

ELEVATOR "C"

Status:	Demolished
Date:	Building permit application March 10, 1922; completed October, 1922
Designer:	Fegles Construction Co.
Builder:	Fegles Construction Co.
Cost:	$635,000
Foundation:	Unknown
Basement:	Unknown
Bins:	Main bins 5 x 2 in parallel rows; 20' in diameter Interspace bins 8 x 1, of unconventional square form within interspace between four main bins 10 outerspace bins, convex 1/3 circle outer walls Non-tangential link wall connections between bins; link walls do not connect bins at their closest points, but towards the center line of the building; straight link walls; those of any four main bins meet to form a square bin in the interspace; between every square bin is another interspace bin the walls of which are formed by transversely adjacent main bins and the transverse link walls; outerspace bins extend back to the longitudinal link walls Reinforcing details unknown
Gallery/ Workhouse:	Monolithic concrete with exterior pier and panel features
Marine Tower:	Movable, structural steel clad in corrugated iron

REFERENCES: The original Buffalo City Hall plans have been lost. The costs are from the City Plans Book for 1922 and the dates from city building permits. Structural details are from a Sanborn Fire Insurance Map and articles in American Elevator & Grain Trade 41 (15 October 1922): 243; 41 (15 December 1922): 397.

GREAT EASTERN ELEVATOR

Status:	Demolished 1948
Date:	Building Permit application January 23, 1901; approved February 8, 1901; work began October 1, 1900; completed by September, 1901
Designer:	H.R. Wait, Chief Engineer to Steel Storage & Elevator Construction Company (SS&ECC)
Builder:	Steel Storage & Elevator Construction Company Steel fabrication by the Indiana Bridge Company of Muncie, Indiana; concrete basement by Donnelly Construction Company
Cost:	$150,000
Foundation:	1,000 wooden piles
Basement:	Full height (9') in reinforced concrete; 33" square pillars support 36" thick bin slab; structure incorporated landings for the tanks and slab reinforced concrete hoppering; outer tanks had conveyor tunnel basements; cupped concrete foundation dishes; basement rhomboidal in plan
Bins:	Capacity 2,500,000 bushels Main bins 68, free-standing cylindrical bins of 15'-6" on 16' centers; bins approximately 70' high and placed on concrete basement works; Bins arranged in rhomboidal group of 6 x 11 bins in interlocking rows; 2 additional small bins placed in the NW corner of structure; Total capacity of small bins 1,000,000 Large bins, 10 free-standing approximately 55' in diameter and 80' high; rise from grade (not on basement works); arranged around the periphery of central core of small tanks; to the south there were 4 large tanks in a single row; to the north 6 large tanks in 2 interlocking rows comprised an inner row of 4 tanks and an outer row of 2 tanks Capacity of large tanks 1,500,000 bushels

Small and large tanks completed as part of the same building program in 1901

Gallery: Overhead gantry type of structural steel clad in corrugated iron; gantry over central small bins particularly large and features low pitched roof; two secondary and much smaller conveyor galleries served outer row of large bins on the north side of structure

Workhouse: Structural steel clad in corrugated iron

Marine Tower: Single thin lofting tower in center of west elevation; larger workhouse associated with two movable marine towers on eastern elevation

REFERENCES: The original Buffalo City Hall plans survive. The dates are from city permits and the costs from the City Plans Book for 1901. American Elevator & Grain Trade 20 (15 August 1901): 59, describes the elevator. The small bins were almost completed before work commenced on the outer large bins. The Buffalo Express of March 31, 1901, notes the pioneering use of "cement and twisted iron" in the basement works. The progress on the project is reviewed in the Buffalo News of May 10, 1901, September 21, 1902, and February 16, 1902. The Buffalo News of October 13, 1901, shows the Dakota and the Great Eastern complete with large bins in the background. The general arrangements at the elevator may be studied from an aerial photograph appearing in the Northwestern Miller, 138 (30 April 1924): 498.

IRON ELEVATOR
(Lake Shore Railroad Elevator)

Status:	Demolished 1940
Date:	Building permit application April 3, 1901; approved December 31, 1901
Designer:	James MacDonald
Builder:	James MacDonald Engineering Company, Chicago
Cost:	$100,000
Foundation:	Wooden piles
Basement:	Full height (8') of reinforced concrete bracketed basement columns support reinforced concrete slab hoppering and provide the landings for the bins
Bins:	Capacity 500,000 to 600,000 bushels Main Bins, 36 in 6 x 6 rows of interlocking cylindrical bins 17' in diameter; 63' deep Interspace bins: 60 between main bins of curved "triangular" form Outerspace bins: 22 between outer cylinders of curved "triangle" form Elliptical bins: 6 eye-shaped bins, one at the end of every row of main bins; single elliptical bin in any one row at the opposite end of the structure to those of adjoining rows; elliptical bins provide an even nest of interlocking bins that sit on the square basement structure; bin system patented by James MacDonald consists of curved pre-fabricated plates of a uniform curvature, equalling 1/6 the circumference of main bins; three such plates assembled on the ground into a "triangular" unit, the interior of which consisted of one interspace bin, and the exterior, 1/6 of a main bin; pre-assembled units lifted into place to form an integrated and standardized nest of main,

inter- and outerspace bins; six such units to every main bin; design produced inter- and outerspaces of very low capacity

Bin Floor: Reinforced concrete

Gallery/
Workhouse: Low gallery of structural steel clad in corrugated iron; workhouse of same extending length of structure

REFERENCES: The James MacDonald Patent No. 662452, September 17, 1900, details the system of construction. The estimated cost of construction is from the City Plans Book for 1901. The American Elevator & Grain Trade 19 (15 January 1901): 304, 20 (15 February 1902) and 20 (15 July 1901) provide details of the structure. The first article includes a bin plan and a lithograph of the completed building. The higher capacity is given by the American Elevator & Grain Trade (15 February 1902); 500,000 bushels is given by the designer.

JOHN KAM MALTING ELEVATOR
(Black Rock Milling)

Status:	Demolished
Date:	1901
Designer:	J. F. Dornfeld, Arch-Eng, Milwaukee
Cost:	$150,000 (including large malt house)
Foundation:	Spread footings
Basement:	Tunnel type
Bins:	Total capacity of 550,000 bushels, including workhouse; free standing steel, 4 x 8, 20' diameter x 62' high, arranged in interlocking rows similar to Great Eastern Elevator
Gallery:	Steel frame, corrugated iron clad
Workhouse:	Steel frame, concrete floors, circular steel bins, capacity of 50,000 bushels
Equipment:	Malt house contained 42 drum germinating machines

REFERENCES: Buffalo DPW Building Permit and plans on file; Henry H. Baxter, personal communication, 31 July 1992. The malt house, a very substantial brick building, survives, but malt production ended with Prohibition. Complex was adopted for feed mill use by Black Rock Milling Co., and is used in 1992 by an insulation distributor.

MONARCH ELEVATOR

Status:	Demolished 1950
Date:	Building permit application August 31, 1905; approved September 6, 1905
Designer:	H. R. Wait, Chief Engineer to Steel Storage & Elevator Construction Company (SS&ECC)
Builder:	Steel Storage & Elevator Construction Company, Buffalo
Cost:	$141,000 ($200,000)
Foundation:	Approximately 1,000 wooden piles
Basement:	Full height, reinforced concrete; basement wall-type with outer walls as segments of polygons
Bins:	Capacity of 450,000 bushels (500,000 bushels) Main bins, cylindrical, 15 in 5 x 3 non-interlocking rows, approx 70' high; 8 interspace bins No outerspace bins
Gallery:	Structural steel clad in corrugated iron
Workhouse:	NW corner of structure, incorporating fixed marine tower

REFERENCES: The original Buffalo City Hall plans could not be found. The estimated cost of construction is from the City Plans Book for 1905; the higher cost for construction excluding equipment is from <u>American Elevator & Grain Trade</u>. The deployment of bins is unclear. The <u>American Elevator & Grain Trade</u> gives a total of forty-six bins when reviewing the structure in 1905. However, the arrangements deduced from contemporary photographs suggest that there were only twenty-three bins. The higher storage capacity is given in the <u>American Elevator & Grain Trade</u> of 1917, the lower figure in the <u>Northwestern Miller</u> (21 September 1927). The building is reviewed in <u>American Elevator & Grain Trade</u> 30 (15 May 1912): 594 and 24 (15 September 1905): 133.

EXTENSION
(Evans Elevator Annex)

Status:	Demolished 1950
Date:	Post 1917
Designer:	Unknown, possibly H. R. Wait
Builder:	Unknown, possibly Monarch Engineering
Cost:	Unknown
Basement:	Tunnel-type with individual concrete dished plinths for bins
Bins:	Capacity 350,000 bushels Four large free-standing bins approximately 55' high; hemispherical steel bottoms rest in dish of foundation plinth
Gallery:	Gantry-type conveyor gallery to Monarch and Evans elevators

REFERENCES: The date of construction is unknown. A photograph appearing in an advertisement in the American Elevator & Grain Trade 36 (15 September 1917): 145, does not show the extension. The Northwestern Miller (21 September 1927): 1100, shows an addition of 350,000-bushel capacity. The Buffalo News (17 June 1950) shows the complex under demolition and exposes many construction features.

PRATT FOODS ELEVATOR

Status: Demolished

Date: 1929

Designer: Possibly Monarch Engineering

Bins: 32 circular and 18 interspace; this bin arrangement appears on an insurance map but a historic photograph suggests fewer, larger bins

REFERENCE: Sanborn Fire Insurance Maps (1916); photographs, and site inspection notes by Henry Baxter; Henry H. Baxter, personal communication, 31 July 1992.

RALSTON PURINA ELEVATOR

MAINHOUSE

Status:	Demolished
Date:	Building permit issued July, 1907
Designer:	James McDonald Engineering Co.
Builder:	James McDonald Engineering Co.
Cost:	$170,000
Foundation:	Wooden piles with concrete foundation slab
Basement:	Full height (12')
Hoppers:	Unknown
Bins:	Capacity 400,000 bushels Main bins 6 x 3, cylindrical 19' in diameter, parallel rows, 70' high Interspace bins 5 x 2 14 outerspace bins; exterior wall straight-sided
Bin Floor:	Unknown
Gallery/ Workhouse:	Steel-frame concrete roof slab, walls plaster on expanded metal reinforcing

REFERENCES: The original Buffalo City Hall plans have been lost. The costs and dates appear in the Buffalo Evening News, 27 July 1907. Details of the structure come from the American Elevator and Grain Trade, 26 (15 June 1908): 633; 40 (15 September 1921): 175.

ELEVATOR "B"

Status:	Demolished
Date:	ca. 1917
Designer:	A. E. Baxter Engineering Company
Builder:	Unknown
Cost:	Unknown
Foundation:	Unknown
Basement:	Full height on pillars
Bins:	Capacity, 300,000 bushels 36 rectangular main bins, flat exterior; Structure incorporates mill between old (Husted) and new elevators
Gallery/ Workhouse:	Monolithic concrete workhouse; possibly first slip-formed workhouse in Buffalo.

REFERENCES: The original plans are in long term storage at the Buffalo and Erie County Historical Society and are not available for inspection. The above information was taken from the Northwestern Miller 17 (1920): 10, and the American Elevator & Grain Trader (15 September 1921): 175; 36 (15 September 1917): 161.

RIVERSIDE MALTING ELEVATOR
(Fleischmanns)

Status:	Demolished c. 1965
Date:	City permit issued June 1907; Plans show 10 circular bins, but 20 were actually built
Designer:	Steel Storage and Elevator Construction Company, Buffalo
Builder:	Steel Storage and Elevator Construction Company, Buffalo
Basement:	Separate basement
Bins:	Reinforced concrete; 20 16' diameter x 60' high, and 12 interspace Total capacity of 200,000 bushels
Hoppers:	8 concrete slabs in the shape of elliptical, 45 degree sectors, pitched 45 degrees and supported by 8 I-beams
Conveyors:	Instore and outstore 16" screw conveyors
Marine Leg:	A separate permit was obtained for a marine leg to unload Erie Canal boats

REFERENCE: Buffalo DPW Building Permit, with plans; Sanborn Fire Insurance Map (1916); Henry H. Baxter, personal communication, 31 July 1992.

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